Habitat loss and landscape degradation: the disastrous outlook for vertebrate fauna in central western NSW

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ABSTRACT

The Central West and Lachlan Catchments lie west of the Great Dividing Range in central NSW and have been subjected to extensive land clearing, grazing and agricultural pressures beginning in the 1820s. Many vertebrate species are known to have disappeared from these catchments but reliable data for species diversity, distribution, abundance and conservation status are not available. For this assessment of the diversity and status of the vertebrate fauna in these catchment areas a comprehensive database of vertebrate records was established, species distributions mapped, faunal communities determined by pattern analysis and conservation status determined at a regional level. The extent of post-European human-induced landscape change was evaluated by assessing the degree of habitat loss, loss of landscape function and resilience through changes to the water cycle, soil and energy flow and the impact of invasive species, diseases and agricultural pollution.

Of the 595 vertebrate species verified for these catchments, 6% are introduced, 12% have been listed in NSW under the *Threatened Species Conservation Act 1995*, 4% by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999,* 40% are regionally vulnerable, 20% regionally endangered and 2% likely to have become extinct in the region. Overall we estimate that 64% (382) of species are declining. These statistics present a grim picture of the survival of vertebrates in these catchments and potentially for the sheep-wheat belt of eastern Australia. The extreme loss of habitat and its poor condition across much of these catchments followed by serious changes to the functioning of the landscape provide clear reasons for the catastrophic decline of vertebrates in this landscape. If this serious decline in the Central West and Lachlan catchments is to be halted, strategies aimed at habitat and landscape restoration must be developed. Current strategies based on Threatened Species management plans and ad hoc planting for revegetation have not produced results. We need a radical rethink.

Key words: Central West catchment, Lachlan catchment, NSW, vertebrate diversity, distribution, status, communities, habitat loss, habitat condition, human-induced landscape change, landscape function.

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Introduction

In this paper we discuss the insidious broadscale impacts of human induced landscape change (threatening processes) on wildlife in the Central West of New South Wales (NSW). These impacts are broadscale in both space and time and need to be considered together with the predicted impacts of climate change. The combined impacts are likely to be cumulative, and in some cases synergistic, thereby further adversely impacting the distribution, diversity and abundance of vertebrate fauna in the region which is already under great stress. By comparison disasters such as fires, droughts and floods are definable catastrophic events with impacts that can be measured and assessed.

Study area

The study area covers the Central West and Lachlan Catchment Management Areas (CMAs), approximately 25% of the land surface of NSW. This area extends from Oberon to Bourke and Crookwell to Ivanhoe, from Australia's oldest inland agricultural lands in the east to the rangelands of the west (Figure 1). It includes the catchments of the Lachlan, Macquarie, Bogan and Castlereagh Rivers and is an ecological transition zone ranging from the temperate Bassian zone in the east (Date *et al*. 2000) to the arid Eyrean zones in the west (Bauer and Goldney 2000). It also encompasses portions of eight biogeographic regions (Figure 2) and four botanical divisions (Anderson 1961).

Post-European human-induced landscape change

Since European settlement this landscape has been dramatically altered resulting in a loss of native vegetation cover, destruction of soil quality and structure, disruption of the landscape hydrology and the introduction of pests and weeds (Bauer and Goldney 2000; Letnic 2000; Kerle *et al*. 2007; Windsor *et al*. 2004). Early descriptions (1813-1841) of the

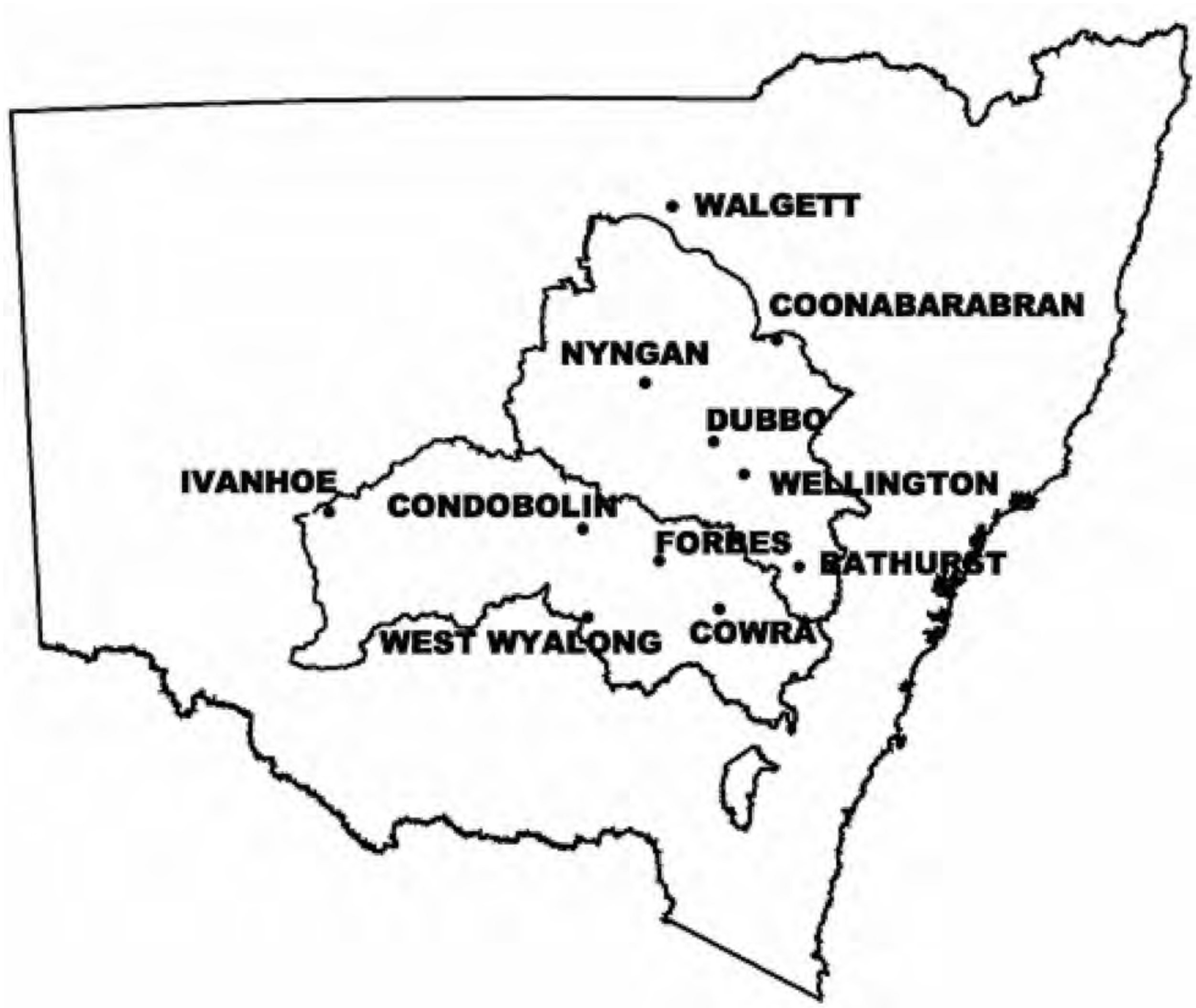


Figure 1: Location map – Central West CMA(Bathurst to Nyngan) is to the north of the Lachlan CMA(Cowra to Ivanhoe)

upper Macquarie River catchment by explorers and settlers provide a picture of the condition of the rivers, vegetation of the riverbanks and plains and fauna at the time of European settlement as well as the rapid changes that subsequently occurred (Windsor *et al.* 2004). The Macquarie River at Bathurst was described as 'clear and beautiful' in a dry season; the Bathurst plains were treeless grasslands, possibly the product of a severe winter microclimate and cracking clays underlying the alluvial soils; the rivers had 'fringes of fine swamp oaks' and the hill slopes were treed. Fish were abundant in the Fish (hence it's name), Campbell's and Macquarie Rivers and platypus, turtles, frogs, emus and waterfowl were very abundant. Within 13 years of settlement European impact was unsustainable. The land was rapidly stocked with sheep and cattle, the first crops planted in 1819 and vegetation was extensively cleared (Windsor *et al.* 2004). Prior to the establishment of boiling down facilities to produce tallow from 1843, destocking was not possible under adverse conditions in the early days of the Bathurst area and overgrazing occurred regularly (Pearson and Lennon 2010).

Grazing and clearing for farming spread in surges west from these initial settlements across the catchments. The area of inland NSW sown with crops each year in the wheat belt (excluding fallow or ploughed land) has been estimated from Australian Bureau of Statistics reports (Bedward *et al.* 2007). By 1900 cropping occurred mostly along the eastern edge of the wheatbelt but by the 1920s it was well established with more than 50% of these catchments cropped, cleared and thinned (Goldney and Bowie 1990; Bedward *et al.* 2007). In the 1940s cropping was intensified within land already cleared with further expansion in the 1950s and 1960s. By the 1970s expansion and intensification were occurring in the western rangelands with further intensification in the eastern third of the wheatbelt (Bedward *et al.* 2007).

The European impact on the landscape of western NSW differed from the events that occurred in the east. The fragility of the arid ecosystems was recognised by some landholders over 100 years ago and documented in the Royal Commission of 1901, but is still not well incorporated into landuse management practices (Letnic 2000). Expansion of grazing was initially restricted by the need to remain close to watercourses for watering stock. By 1840 river frontages along the Barwon, Murrumbidgee, Lachlan and Murray were taken up for cattle and sheep runs and extended to the Darling frontages by the 1850s. The pattern of occupation and development changed significantly in the 1870s and 1880s with construction of wells, bores

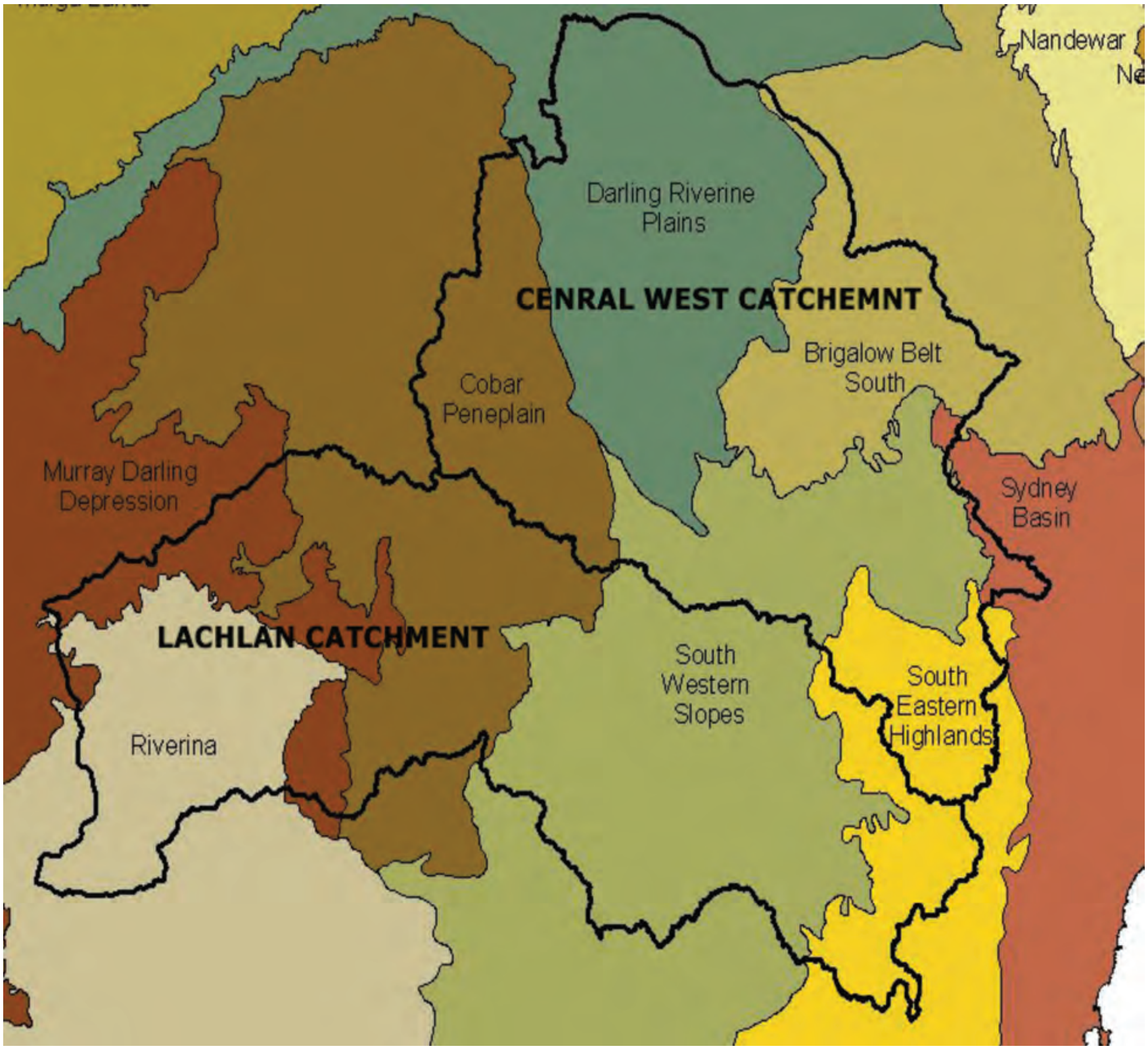


Figure 2: Biogeographic regions of the Central West and Lachlan Catchments

and tanks enabling permanent expansion of stock runs into the dryland (Lunney 1994).

Fencing of stock runs began around this period and this, along with the use of timber for construction of dwellings, firewood, lining of well and mine shafts and for stock fodder led to mass clearing of timber from large areas. The clearing of timber around the many active mining sites and locations increased dramatically following the arrival of steam engines and dependent machines such as mining batteries from around 1880 (Barker 1992). A combination of massive over stocking, rabbit plagues and drought led to the desertification of the landscape which led to the Royal Commission of 1901. The severity and extensiveness of the devastation of this area cannot be overestimated. Vast areas suffered from a complete loss of vegetation and soil to a significant depth and other areas were denuded of vegetation and then buried by the massive volumes of shifting soil. There are many dramatic descriptions from the transcripts of the Royal Commission (Lunney 1994).

With continuing dry conditions from the 1910s to the 1950s, it was not until the 1950s that the landscape began to be able to recover. Most anecdotal evidence from older landholders clearly indicated that the growth of 'woody weeds' began at this time. From the 1950s to the 1990s the landscape has had good rainfall overall, enabling massive agricultural expansion to occur with the majority of current agricultural and land management practices being developed within the last 50 years of relatively good rainfall, compared with the preceding dry conditions in the first half of the twentieth century (Kerle *et al.* 2007).

As a consequence of the rapid and dramatic changes that occurred in the landscape over 150-160 years after the first crossing of the Blue Mountains in 1813, the extant native vegetation is predominantly regrowth of various ages (Goldney *et al.* 1997) and the soft spongy soils of this landscape have disappeared. This level of vegetation resilience is remarkable but does the landscape recover to its former capacity? Bauer and Goldney (2000) argue from historical records that land degradation, the nature and extent of vegetation clearing, rabbit and sheep eruptions, the development of the pastoral and agricultural industries, the dispersal of cats and foxes and drought events reveal

complex links between anthropogenic and natural events and the patterns of vertebrate decline.

Habitat loss

The extent of the loss and modification of native vegetation in the Central West of NSW is evident from mapping of remnant vegetation in NSW. However, the impact of this on vertebrate diversity and trends in abundance requires assessment of the availability of habitat across each species' distribution. Habitat requirements vary between species and include all factors supporting species' life history strategies: food, nesting and refuge resources through the full life cycle and across the entire range of the species. While some vertebrate species may have specific habitat requirements and narrow feeding niches they rarely respond to plant species *per se*, but rather to a complex set of attributes. These include plant life-form, successional stage, structure and density of the vegetation, landform attributes, presence of water and type of water body, extent and connectivity of the habitat and seasonality of food resources.

Assessment of habitat availability at a landscape scale is difficult and mapping of vegetation communities is most frequently used as a surrogate. But is this available habitat? Vegetation mapping focuses on describing vegetation communities and their component plant species and spatially representing these as communities, associations or alliances. Mapped resolution can vary significantly depending on the baseline data available and this is supplemented by modelling that approximates reality. While this is an appropriate starting point it is important that habitat attributes including species specific critical resources are also incorporated for the purpose of vertebrate species management. Factors such as variation in flowering time between species of the dominant Eucalypt are important determinants and whether the dominant species is *Eucalyptus melliodora, E. albens* or *E. viminalis* (for example) may be of little consequence. The area of remnant patches, their condition and connection to other patches are all key attributes in the assessment of habitat suitability.

For this assessment of habitat within the Lachlan and Central West Catchment Management Areas we have used vegetation mapping as the basis for the definition of broad habitat types (BHTs). DEC (2006a,b) identified 75 broad vegetation types (BVTs) within the two CMAs and these have been aggregated into vegetation formations defined by Keith (2004). Further refinement of the BHT definition was based on broad topographic variation which also reflected an east-west gradient, and substrate. A broad habitat type map was constructed (Figure 3). The fourteen BHTs defined from these aggregated BVTs are:

1. Tall Open Forests - Ranges and Tablelands
2. Grassy Woodlands - Ranges and Tablelands
3. Grassy Woodlands - Slopes & Alluvial Plains
4. Grasslands - Ranges, Tablelands and Slopes
5. Grasslands - Alluvial Plains
6. Dry Sclerophyll Forests - Ranges, Tablelands and Slopes
7. Dry Sclerophyll Forests – Plains
8. Freshwater wetlands - Swamps, permanent wetlands, ephemeral wetlands, dams etc.
9. Forested Wetlands - Riverine corridors and floodplains – River Sheoak and River Red Gum.
10. Semi-arid Woodlands – Plains
11. Semi-arid Woodlands - Rocky Outcrops
12. Mallee Woodlands: Dunes and Sandplains - Mallee woodlands/shrublands
13. Arid Shrublands - Chenopod shrublands
14. Arid Shrublands - Tall shrubland/Low woodland.

A description of these BHTs is provided in Goldney *et al.* (2007).

The remnant habitat in the east of the two CMAs is dominated by dry sclerophyll forests while the semi-arid woodlands, mallee and chenopod shrublands are dominant in the west. Over the entire area the remaining native vegetation cover is estimated to be 39% (61% lost) but this varies substantially across the study area. Percent BHT cover for each of the 1:100,000 mapsheets within the two catchment areas ranges from 3% to 100%, much of which is post clearing regeneration(Goldney *et al.* 1997; Goldney *et al.* 2007) (Figure 4).

The percent cover of BHTs per mapsheet has been divided into four classes of fragmentation based on McIvor and McIntyre (2002) and with division of their fragmented class into fragmented and highly fragmented. The cover classes are:

1. Relictual (<10% cover) – 11%, (9) of mapsheets
2. Highly fragmented (10-30% cover) – 35% (28) of mapsheets
3. Fragmented (30-60% cover) – 20% (16) of mapsheets
4. Variegated (60-90% cover) – 23% (18) of mapsheets
5. Intact (>90% cover) – 10% (8) of mapsheets

The majority of relictual and highly fragmented 1:100,000 mapsheets are within the eastern two-thirds of the two CMAs while the majority of western mapsheets have more than 60% cover (Figure 4). The mapped remnant habitat includes degraded habitat along drainage lines and on ridges that are unsuitable for agriculture, especially in areas with relictual vegetation cover, some larger patches in degraded condition and mapsheets with 100% cover which is dominated by dense woody shrub growth and is a mixture of healthy and degrading habitats.

Representation of these BHTs in public lands (National Park estate and State Forest) varies not only between habitat types but also between the Central West and Lachlan CMAs. In the Central West 10% of extant native habitat occurs within the reserved lands compared with 13% in the Lachlan catchment and the distribution and extent of each BHT within reserved lands varies from three quarters of Tall Open Forests to almost no Arid Shrublands. The percentage of each BHT within each CMA and within reserved lands is provided in Tables 1 and 2.

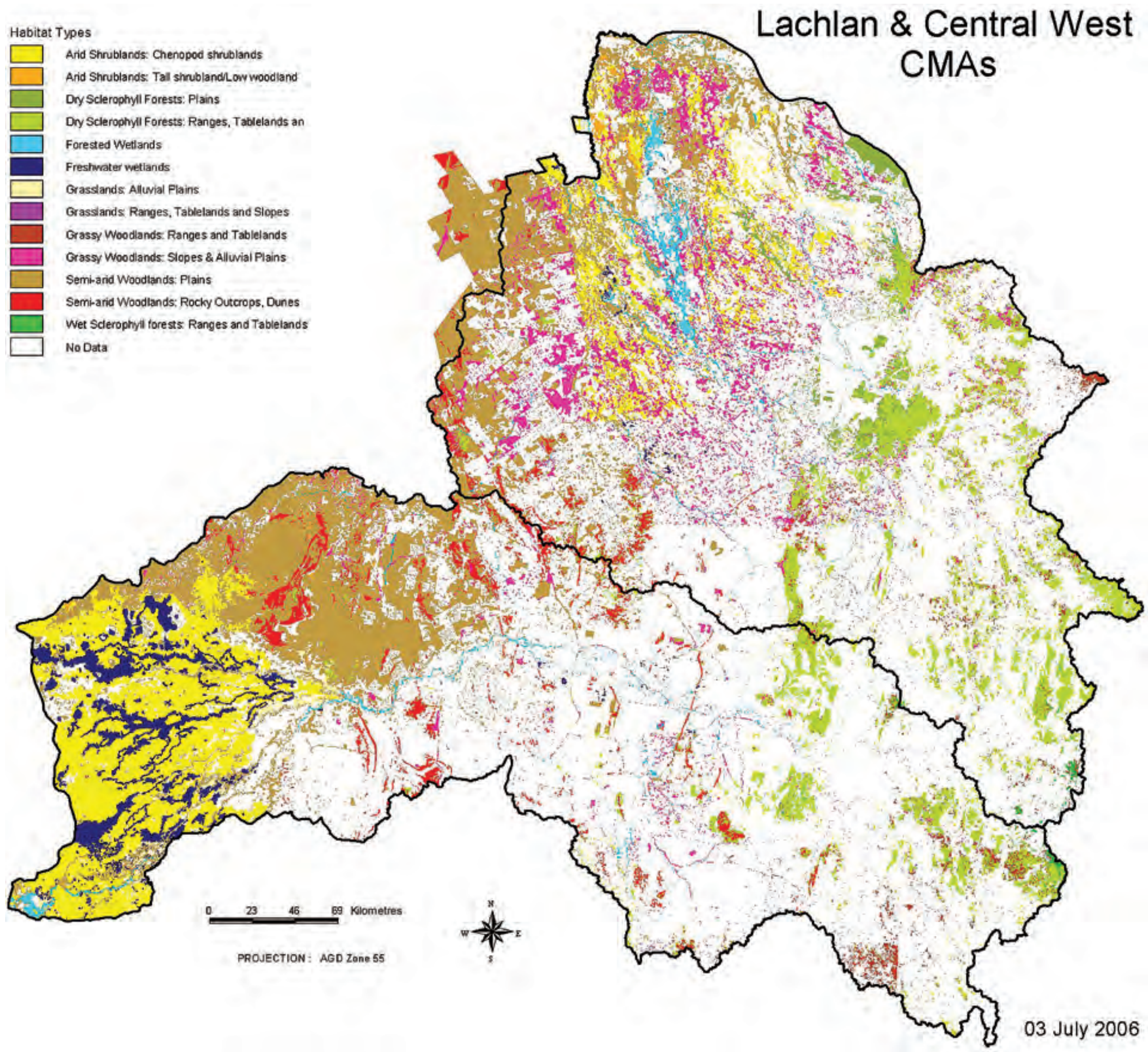


Figure 3: Remnant habitat in the CW and L CMAs

Loss of landscape function and resilience

The maintenance of effective landscape wide ecosystem function is fundamental for sustainable productivity, for both natural and human production. Large-scale anthropogenic landscape modification has rarely been evaluated as a threatening process but it is known to be a critical element in the loss of species diversity, landscape function and resilience (e.g. Brussaard 1997; Duponey *et al.* 2002; Eswaren *et al.* 2001; Goldney and Bauer 1998; Zhou *et al.* 2006). Such adverse broadscale landscape impacts include changes in the hydrological, nutrient and carbon cycles, vegetation loss, soil loss and changes to the soil structure, and malfunctioning of energy interception and energy flow pathways. The impact of some activities may be perceived as being quite local but the actual impact can be extensive, affecting processes at both micro and macro scale.

The water cycle

The movement of water across the landscape differs between functional and degraded landscapes. In a functional landscape rainfall, including from intense storms, will be distributed locally, infiltrating the soil and building up reserves of moisture. In a degraded or dysfunctional landscape a significant proportion of this will become runoff, resulting in a loss to the local landscape (Tongway and Ludwig 2011). Infiltration is enhanced by the presence of a higher density of vegetation cover that reduces the momentum of the overland flows. Litter, sediments and nutrients are also trapped rather than being lost in runoff. In highly functional landscapes even small rainfall events can be captured in the soil and are especially beneficial for ephemeral plants or fungi. Conversely in a landscape with reduced vegetation cover and compacted soils there is little infiltration and increased erosion (Tongway and Ludwig 2011).

Changes in the optimal functioning of the water cycle at all scales across a landscape, results in water leakage rather than water recycling (Kravcik *et al* 2007) and the semi-closed pre-European water cycle malfunctioning. Under such circumstances surface hydrology is increasingly characterised by rapid non-soil penetrating runoff. Follow-on impacts can include more rapid and higher energy run-off, depressed baseline stream flows, increased soil erosion, adverse impacts on soil micro-organisms and their functional cycles, and increased soil temperature.

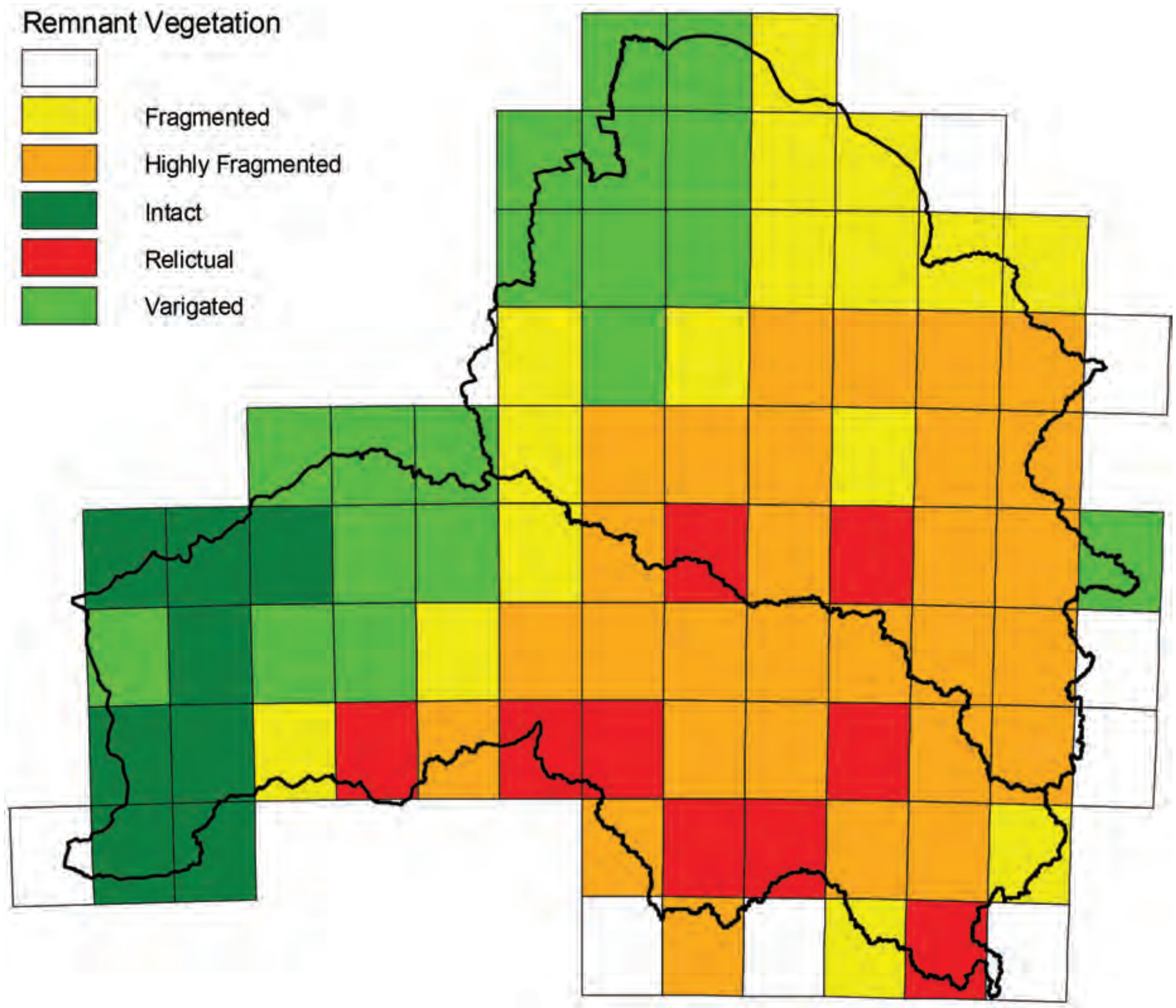


Figure 4: Percent cover of Broad Habitat Types within each 1:100,000 mapsheet of the Central West and Lachlan Catchment Management Areas. The colour coding represents the following fragmentation classification: relictual 1-10% cover, highly fragmented 11-30% cover, fragmented 31-60% cover and variegated 61-90% cover based on a modification of McIvor and McIntyre (2002).

Table 1: Distribution and extent of each BHT (Broad Habitat Type) in the Central West Catchment and the proportion of each found within the National Park estate and State Forests.

Broad Habitat Type	Within Reserved Lands (ha)	% Extant Habitat in Reserve System	Extant Habitat in Catchment (ha)	Extant Habitat as % of Total Catchment Area
Arid Shrublands: Chenopod shrublands	34	0.01	343252	3.73
Arid Shrublands: Tall shrubland/ Low woodland	0	0.00	20467	0.22
Dry Sclerophyll Forests: Plains	60614	40.11	151138	1.64
Dry Sclerophyll Forests: Ranges, Tablelands and Slopes	173117	30.57	566226	6.15
Forested Wetlands	7652	6.27	122113	1.33
Freshwater wetlands	39	0.39	10035	0.11
Grasslands: Alluvial Plains	0	0.00	47268	0.51
Grasslands: Ranges, Tablelands and Slopes	6658	2.17	307260	3.34
Grassy Woodlands: Ranges and Tablelands	12614	22.86	55189	0.60
Grassy Woodlands: Slopes & Alluvial Plains	22558	3.49	646565	7.03
Mallee: Sandplain & Dune	3508	9.67	36294	0.39
Semi-arid Woodlands: Plains	25612	3.26	786305	8.55
Semi-arid Woodlands: Rocky Outcrops, Dunes	5372	6.32	85008	0.92
Tall open forests: Ranges and Tablelands	5511	62.08	8876	0.10
Grand Totals	323289	10.15	3185995	34.63

Table 2. Distribution and extent of each BHT (Broad Habitat Type) in the Lachlan Catchment and the proportion of each found within the National Park estate and State Forests.

Broad Habitat Type	Within Reserved Lands (ha)	% Extant Habitat in reserve system	Extant Habitat in Catchment (ha)	Extant Habitat as % of Total Catchment Area
Arid Shrublands: Chenopod shrublands	14003	1.34	1041460	12.30
Arid Shrublands: Tall shrubland/ Low woodland	356	9.86	3613	0.04
Dry Sclerophyll Forests: Ranges, Tablelands and Slopes	102450	33.78	303292	3.58
Forested Wetlands	2243	4.52	49597	0.59
Freshwater wetlands	3013	0.98	306251	3.62
Grasslands: Alluvial Plains	1534	3.79	40477	0.48
Grasslands: Ranges, Tablelands and Slopes	126	0.15	85335	1.01
Grassy Woodlands: Ranges and Tablelands	14967	22.20	67414	0.80
Grassy Woodlands: Slopes & Alluvial Plains	14050	16.51	85110	1.00
Mallee: Sandplain & Dune	177387	34.46	514757	6.08
Semi-arid Woodlands: Plains	94835	12.45	761571	8.99
Semi-arid Woodlands: Rocky Outcrops, Dunes	32189	14.88	216293	2.55
Tall Open Forests: Ranges and Tablelands	6180	77.48	7976	0.09
Grand Totals	463332	13.30	3483146	41.12

Increased runoff in streams can lead to stream incision, the breaching of geomorphic thresholds and to significant sediment transport with adverse impacts on instream biodiversity as well as on riparian vegetation (Kravic *et al* 2007; Tongway and Ludwig 2011).

Loss of native vegetation has also impacted on the hydrological cycles across the landscape. It has been calculated that prior to clearing 99% of rainfall was accounted for by active harvesting by native vegetation and evapotranspiration, resulting in limited runoff (Silberstein *et al*. 2004). Conversely stream flow from catchments and groundwater recharge rates have been increased by at least two orders of magnitude (George *et al.* 1995; Silberstein *et al.* 2004). Change in the ability of the soil to absorb and retain rainfall was remarked upon by landholders as early as the 1901 Royal Commission:

> *Through the soil having been trodden hard it now takes 10 inches of rain to do as much good as 5 inches formerly did. (G. Riddoch, managing partner of Weitangera Station, Wilcannia District) (Quoted by Lunney 1994).*

Most of the original aquatic ecosystems in the central west have been significantly modified since European settlement. Rivers have been regulated, channels and floodplains drained, extracted or diverted and these modifications have had significant impacts on flow patterns across the landscape. Features such as swampy meadows were once common in the Australian landscape but are now rare as a result of activities including clearing, draining, swamp burning and grazing (Mactaggart *et al.* 2008). Riparian hydrology has become characterised by changes in flow duration, over-extraction, stream incision causing disconnection of instream flow from the adjacent floodplains, rapid draining of the surrounding landscape by incised streams and creek and river flows reaching greater peaks more rapidly while subsequent baseline flows are much lower in degraded watercourses (Brierley *et al*. 1999; LeMaitre *et al.* 2007; Callow and Smetten 2007). In general, the requirement for profitable farming is for greater reliability of water supply while the natural systems have evolved with a highly irregular pattern of flow and flooding. This change is recognised as a significant factor in loss of biological diversity and ecological function as demonstrated by the listing of 'Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands' as a threatening process under the *Threatened Species Conservation (TSC) Act 1995* (NSW Scientific Committee 2002) (Hatton and Nulsen 1999; Boulton 2000; Tickner *et al.* 2001).

On a national scale changed hydrology has been identified as a threatening process in the Central West and Lachlan catchments (Sattler and Creighton 2002).

Soil degradation

Soil erosion and dryland salinity are well recognised as degrading processes in the Central West and Lachlan catchment areas (Please *et al*. 2002). The impact of the loss of soil quality is also critical in the maintenance of landscape function. Loss of soil quality is indicated by the loss of structure, carbon, soil biota and nutrients and trace elements.

Change in soil structure and quality were observed to be occurring soon after the introduction of stock into this region. This was noted by landholders in 1880/81 and reported to the 1901 Royal Commission:

> *The ground was soft, spongy and very absorbent. One inch of rain then produced luxurious growth of fresh green grass. (J. Cotton Cobar district, Quoted in Lunney 1994).*

Clearing of deep rooted native vegetation changed the hydrological cycle, removed the greatest source of organic matter and eliminated suitable micro-environments for soil biota (McKenzie *et al.* 2004). Soil structure has been destroyed through disruption of the A horizon and exposure of the B horizon, loss of the A horizon after

clearing and ploughing, loss of organic matter and natural nutrients to support soil biota and compaction resulting from grazing pressure (McKenzie *et al.* 2004).

Vast quantities of organic carbon were lost with the clearing and subsequent burning of native vegetation as European settlers established grazing and farming enterprises across this landscape. It represents a shift in the balance between organic carbon stored above and below ground with the dominant above ground biomass being removed from the carbon cycle. The loss of organic matter in the soil is also implicated in the loss of soil fertility and structure, the water holding capacity of the soil and soil salinity (Guo and Gifford 2002; Heenan *et al.* 2004; Yates *et al.* 2000).

Changes in energy flow

The loss of native vegetation, exposure of bare soil as a result of overgrazing or through phases in cropping strategies and soil compaction result in the loss of considerable cooling capacity within the landscape and causing landscape over-heating (Kravic *et al.* 2007). The physiological activity of living organisms doubles with every 10^0C rise in temperature to an optimal point with further heating likely to cause death from heat stress or desiccation. Landscape overheating at landscape level is likely to lead to lower productivity and a depressed carrying capacity with adverse flow on impacts for vertebrate and invertebrate ecology.

Impact on vertebrate populations

The pre-European landscape appears to have been a system in equilibrium, with semi-closed cycles operating at all scales (water, carbon and nutrient cycles). Energy interception appears to have been optimal as were the plant cooling processes (Kravic *et al.* 2007). The overall system appears to be either an aggrading system, where resources are being added to, or largely contained within the system and therefore in equilibrium. Such systems have been eloquently described by Tongway and Ludwig (2011) in their pulse-growth model. In contrast degrading systems are those in which resources are being lost at all scales and system cycles leak to the point that outputs are greater than inputs. Such landscapes are in the process of desertification (Bauer and Goldney 2000). Deep incision of watercourses is one symptom of this process and occurs across the central west region in a range of soil types. Incision is usually evidence that both ecological and geomorphic thresholds have been crossed and ecological resilience has been lost. The potential for self-repairing restoration no longer exists under these circumstances and restoration works need to be undertaken if function is to be restored.

Species losses result from both land degradation and system malfunction and are auto-catalytic. Interruption to or even termination of essential ecosystem processes such as soil digging, transfer of underground fungal spores, pollination, predation follow from species loss. Soil quality has also been impacted by the disruption of these processes in addition to the loss of vegetation with the highly friable and loose soils reported by the early Europeans across this region being long gone. What appeared to the early European settlers, explorers and administrators as a landscape with an inexhaustible fertility and production base (e.g. Macquarie 1815) was illusory, and soon found to have an unexpected fragility (Goldney and Bauer 1998). Charles Darwin in his only inland trip in Australia in 1836 from Sydney to Bathurst during a blistering hot summer drought was able to observe and comment on a landscape already demonstrating the signs of extreme stress (Darwin 1839).

Invasive species

Invasive species are those that occur and thrive outside their usual geographic range and can significantly increase in distribution and abundance in response to human activities. At least 80 vertebrate species and 3000 plant species have been introduced into Australia as well as a large but unknown number of invertebrate species (Olsen *et al.* 2006). The impact of these invasive species is directly related to the changes to the land since European occupation.

Feral Animals

A total of 32 introduced vertebrate species are recorded as occurring within the Central West and Lachlan CMAs (this study). These include seven fish, 11 bird and 14 mammal species. Eight of these species and three introduced invertebrate species have been assessed as being of sufficient threat to native species, populations and ecosystems to be listed as threatening processes under the NSW *TSC Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. Of the species listed there are both predators and those that cause habitat degradation and compete with native vertebrate species. Extensive habitat damage is caused by rabbits, goats, pigs and deer, while honeybees, and some feral bird species (e.g. Common Starling) compete for food and nesting resources. The most significant introduced predators are the European Red Fox, Feral Cat and Feral Pig.

We have little knowledge of the impact of introduced species on native vertebrate fauna in the early years of settlement. Gemmell-Smith (2004) provides evidence that in 1878, there were thousands of wild horses in the Oberon area with one family reportedly culling 6,000 horses. We can only guess at what ecological damage was caused by domestic dogs used for hunting and herds of wild horses roaming freely in the countryside.

Introduced fish species impact on the native fish species directly and through stream and wetland habitat modification. This impact varies between species, with direct predation of native *Galaxis* by Plague Minnow, Redfin and Trout, competition for resources by Redfin (implicated in the decline of the endangered Trout Cod and Macquarie Perch) and Carp causing extensive habitat degradation and modification through uprooting of vegetation and disturbance of sediments (Kerezsky 2011). Introduced fish species are also implicated in the spread of diseases such as the Epizootic Haematopoietic Necrosis Virus (EHNV) to native species. The 'Introduction of fish to fresh waters within a river catchment outside their native range' is listed as a threatening process under the NSW *Fisheries Management Act 1994*.

Weeds

There are many plant species that can be classified as weed species, both native and exotic species. Weeds shade, smother, crowd and compete with native plants for light, nutrients, water, space and pollinators. They can fill natural gaps and prevent regeneration and potentially become so dominant that they create biological deserts (Blood 2003). Those that have a significant detrimental impact or cause serious economic loss to agriculture or the environment are declared as noxious species and under the NSW *Noxious Weeds Act 1993* must be controlled. Other species that invade natural ecosystems and potentially seriously impact on native biodiversity are classified as 'environmental weeds'.

The only listing of weed species as a Threatening Process in NSW which is applicable to the study area is 'Invasion of native plant communities by exotic perennial grasses.' This listing includes 19 introduced perennial grasses which can grow into dense monocultures and cause local and regional declines of many native species and communities. These grasses are implicated in the decline in condition of remnant Endangered Ecological Communities such as White Box, Yellow Box, Blakely's Red Gum Woodland and Grey Box Woodland and of a number of plant species and vertebrate species including Speckled Warbler, Diamond Firetail, Hooded Robin and Grey-crowned Babbler listed in Schedules 1 and 2 of the *TSC Act 1995*. There are many other introduced weed species in the study area including willows, African Boxthorn and blackberry which aggressively invade riparian habitat and woodlands and cause degradation of the remnant habitat. Some native species have also become 'weedy' in their growth, largely in response to the changed conditions in the landscape resulting from grazing and agricultural management practices.

Diseases, pathogens and agricultural pollution

Knowledge of the impact of diseases, pathogens and agricultural pollution on the vertebrate fauna of the central west of NSW is extremely limited and predominantly based on anecdotal information. The fatal amphibian disease Chytridiomycosis caused by the Chytrid fungus *Batrachochytrium dendrobatidis* (Longcore *et al.* 1999) has been observed in these catchments (A Kerle personal observation 2005) but the extent of the impact of this disease on amphibian populations has not been assessed. The disease has been listed as a threatening process under the *TSC Act 1995* and the *EPBC Act 1999* as 'Infection of frogs by amphibian chytrid causing the disease chytridiomycosis.'

Amphibians may also be a casualty from agricultural pollution. Pest control such as locust spraying, nutrient pollution and spray drift from horticultural enterprises are the most significant source of agricultural pollution. There is no empirical research into the impact of these sprays on biodiversity but there is anecdotal evidence. The following observations were provided to us as part of this assessment by a landholder from Goolma in the Central West Catchment:

> *Prior to broadscale locust spraying in 2004, frogs were plentiful in number and variety. During summer 05/06 at the house we had 2 resident green tree frogs (approx stable number) and up to 5 putty coloured frogs [probably Litoria peroni] which is much reduced in number (previously 12-20).*
>
> *Previously we had dozens of small 'grass frogs' with dark brownish skin and iridescent green spots on their sides and thighs. Banjo frogs, and barking marsh frogs were also common prior to spraying. Historically (within last 20 years) Litoria aurea or Litoria alboguttata were present in farm dams.*
>
> *I have not seen frogs or tadpoles in any of our farm dams since locust spraying took place in spring 2004. (C. Cromer pers. comm. 2006)*

Status of vertebrate fauna in central western NSW

Vertebrate species database and mapping

A robust, comprehensive database of vertebrate records was established in 2006 for both the Central West and Lachlan catchment areas. This was compiled from a range of sources and critically reviewed before being accepted into the database. The records were compiled from the following databases:

- Birds Australia: www.birdata.com.au - accessible by members of Birds Australia. These records are from both the first (1976 to 1981) and second (1998 to 2002) Atlas of Australian Birds.
- Australian Museums Data Base: OZCAM (Online Zoological Collections of Australian Museums www.ozcam.gov.au). The participating collections in this database are the Australian Biological Resources Study (ABRS), Australian Museum, Australian National Wildlife Collection, Australian National Insect Collection, Museum and Art Gallery of the NT, Museum Victoria, Queen Victoria Museum and Art Gallery Launceston Tasmania, Queensland Museum, South Australian Museum, Tasmanian Museum and Art Gallery Hobart Tasmania, and the Western Australian Museum.
- NSW Bird Atlasers Inc.: www.nswbirdatlassers.com – a summary of the data held for each mapsheet was purchased by the CMAs and included in the database at that resolution. No date information was provided but most records are post 1981.
- BIONET: www.bionet.nsw.gov.au - records from the collections of the Australian Museum, Department of Environment and Conservation and Department of Primary Industry presented in mapping application.
- Wildlife Atlas (NPWS): This atlas of fauna records is publicly accessible through www.wildlifeatlas.nationalparks.nsw.gov.au. A special license agreement

between DEC and the CMAs allowed the source information to be compiled into the database.

- Fisheries NSW: www.dpi.nsw.gov.au/fisheries – Records held in the NSW Fisheries database were supplied to the project. These were a mixture of observational results from fish surveys and release sites for their re-stocking program.

Additional data were sought from landholders (through personal contact and a publicity campaign), scientific publications, Environmental Impact Statements and Assessments, individual scientists and postgraduate and honours students carrying out research. Where appropriate these data were added to the database.

All data were carefully vetted, and highly improbable records or probable mis-identifications eliminated. The deleted records included species out of range, highly unlikely species as assessed by expert opinion, incorrect location details and incorrectly entered data. Suspect records quarantined within the Wildlife Atlas were also checked and added to the database if considered by an expert assessment to be valid records.

Species lists and distribution maps were produced by aggregating the data into 1:100,000 mapsheets and records classified as pre1985 or post 1985. The classification by date enabled trends in change in species distribution to be evaluated, particularly by comparison with Goldney (1987). Species distributions were mapped using ArcView 3.3, from species presence or absence in 1:100,000 map sheets. There are 44 x 1:100,000 map sheets in the Central West Catchment, whole or part, and 45 in the Lachlan Catchment, with nine mapsheets in common.

The 1:100,000 mapsheet was determined to be an appropriate subdivision of the catchments. It was small enough to allow for meaningful distributional analysis but did not identify specific locations of recorded species. It was hoped that this would encourage engagement by landholders who may be unwilling to identify their property but had some interesting records. Species' habitat preferences could then be used for any further analysis. Only actual records were used for mapping and no distribution modelling undertaken. The absence of a species from a mapsheet, even when it is recorded from surrounding mapsheets may result from either the absence of records or the absence of suitable habitat (cleared or never present). These different reasons would be obscured by modelling.

Vertebrate diversity, distribution and abundance

A total of 424,698 records were included in the combined catchments database. Robustness of the sample size and the minimum number of observations was tested by calculation of species accumulation curves for two of the best sampled 1:100,000 mapsheets. For the Bathurst 1:100,000 mapsheet the curve trended towards the asymptote from approximately 250 species

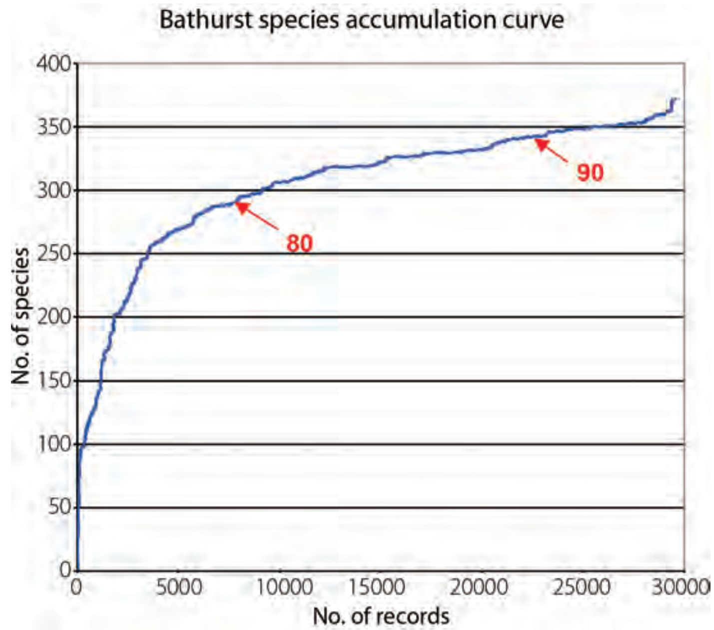
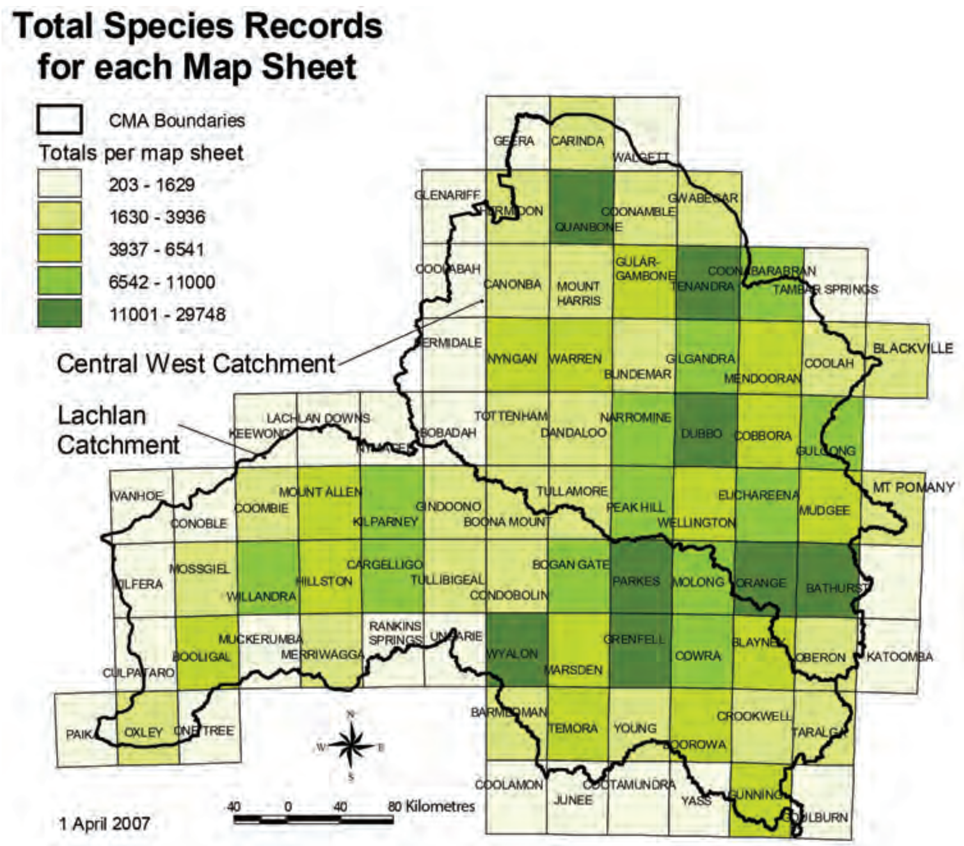


Figure 5: Species accumulation curve for the Bathurst 1:100,000 mapsheet.

recorded (Figure 5). 7,500 observations were required to reach 80% of species records compared with 23,000 observations to reach 90% of species recorded (Figure 5). The Quambone 1:100,000 mapsheet which includes the Macquarie Marshes also has a high number of records. For this mapsheet 80% of species were recorded with approximately 3,500 observations and 90% of species with 5,500 observations. The Quambone mapsheet also has a smaller species diversity than the Bathurst mapsheet and the available habitats differ significantly between the two locations.

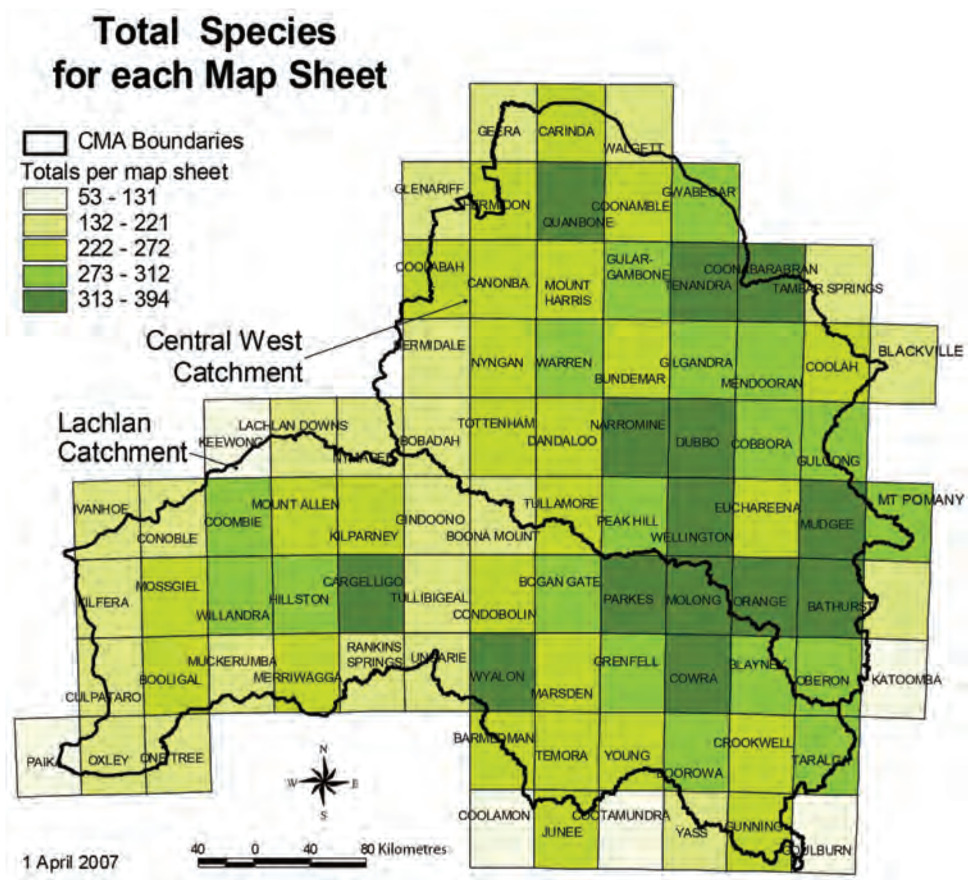
Total records for all species per mapsheet for the Central West and Lachlan catchments are represented on Figure 6. These range from 491 (One Tree) to 29,748 (Bathurst) records. Although a higher proportion of mapsheets in the east of the catchments have a greater number of records it is not possible to determine whether this reflects different levels of survey effort or more species detected and the habitat variability.

The total number of vertebrate species recorded for the two CMAs is 595 including 25 introduced species. As for the number of observations, the recorded species diversity varies substantially between the 1:100,000 mapsheets, ranging from less than 118 (Canbelego) to 394 (Dubbo) species (Figure 7). Variation in species diversity across the catchments is also evident when each of the vertebrate groups is considered individually but there is no consistent pattern between them (Figures 8-12). Overall there is a lower species richness in the west of the catchments but the presence of higher diversity in individual mapsheets is a reflection of a higher number of records, for example Cargelligo has 9064 records, compared with Tullibigeal to the east with 2732 records and substantially more than most of the other nearby mapsheets. There was insufficient data available for the distribution of fish species to be mapped independently of the other vertebrate groups.



Map prepaired for the Lachlan and Central West Catchment Management Authorities.

Figure 6: Total number of records of terrestrial vertebrates per 1:100,000 mapsheet for the Central West and Lachlan catchments.



Map prepaired for the Lachlan and Central West Catchment Management Authorities.

Figure 7: Terrestrial vertebrate species diversity per 1:100,000 mapsheet within the Central West and Lachlan catchment areas.

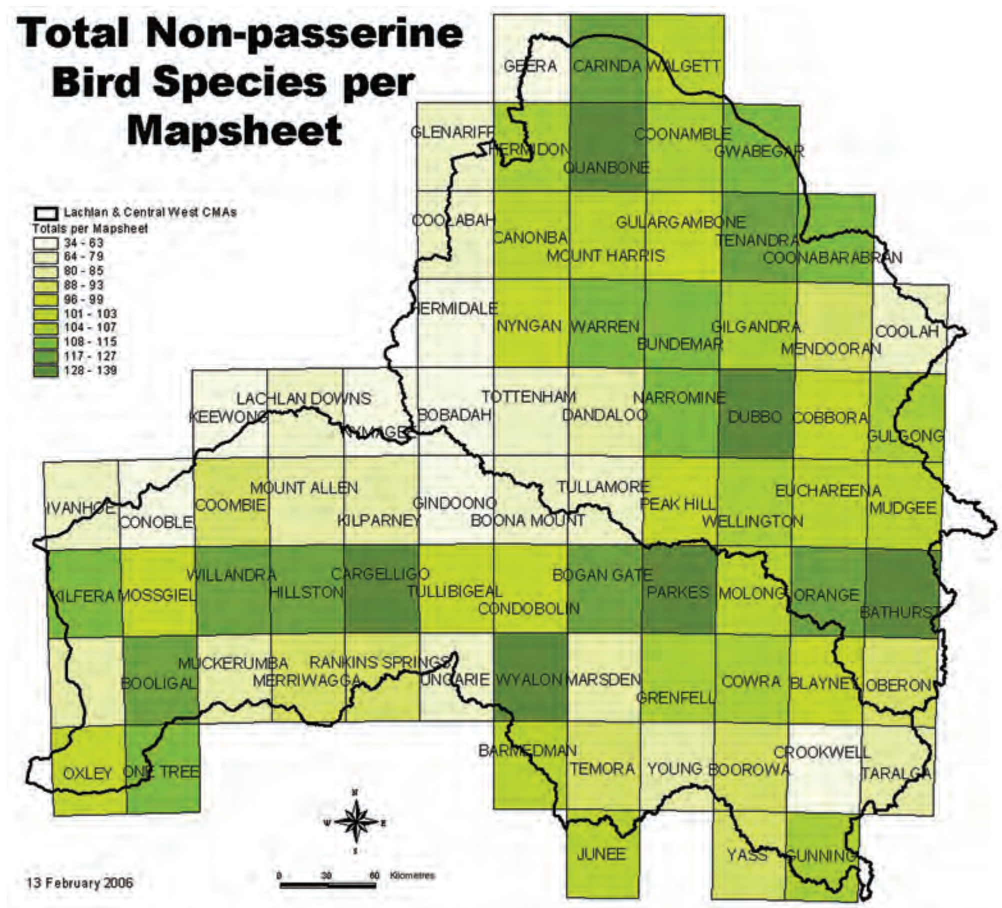


Figure 8: Total number of non-passerine bird species recorded for each mapsheet on the Central West and Lachlan CMAs.

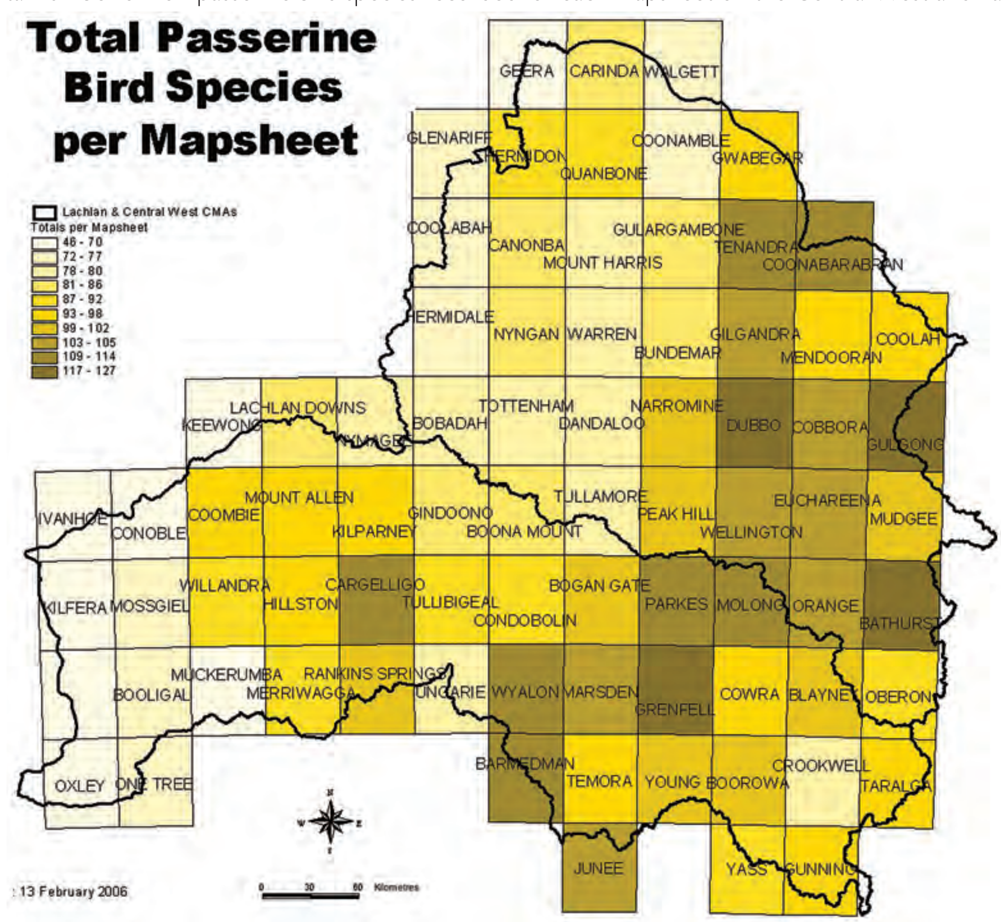


Figure 9: Total number of passerine bird species recorded for each mapsheet on the Central West and Lachlan CMAs.

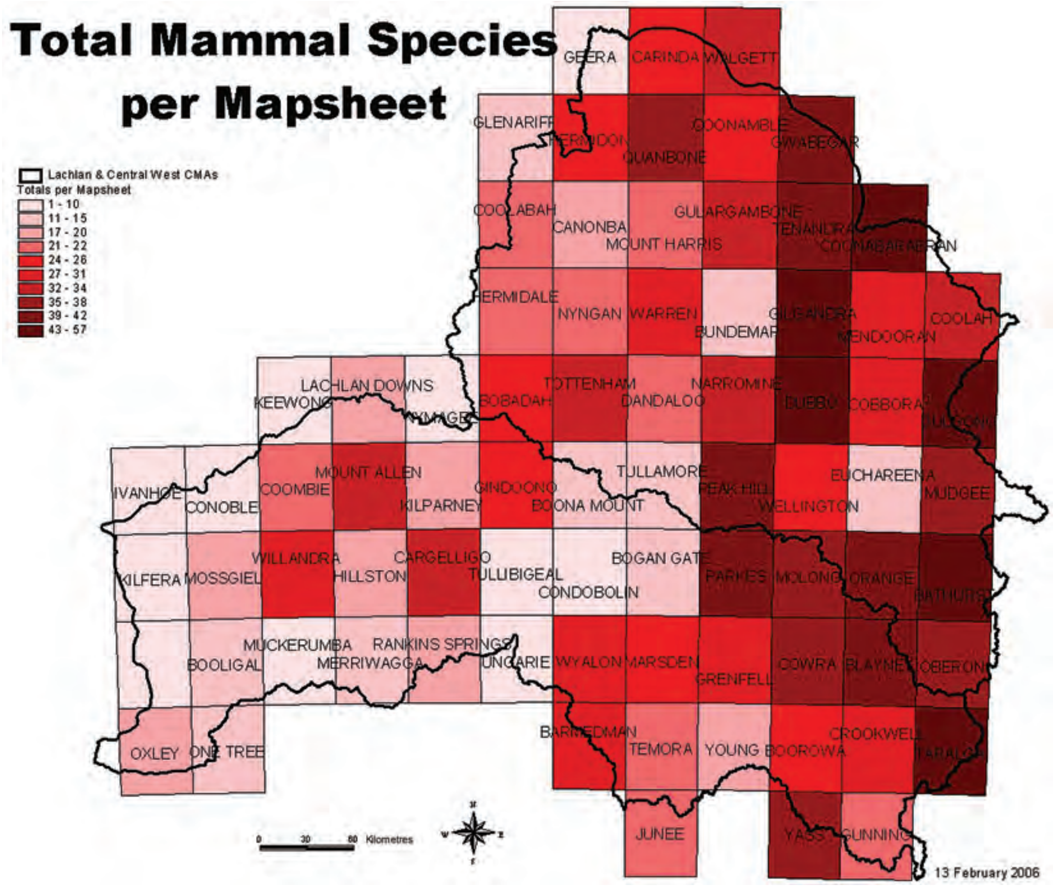


Figure 10: Total number of mammal species recorded for each mapsheet on the Central West and Lachlan CMAs

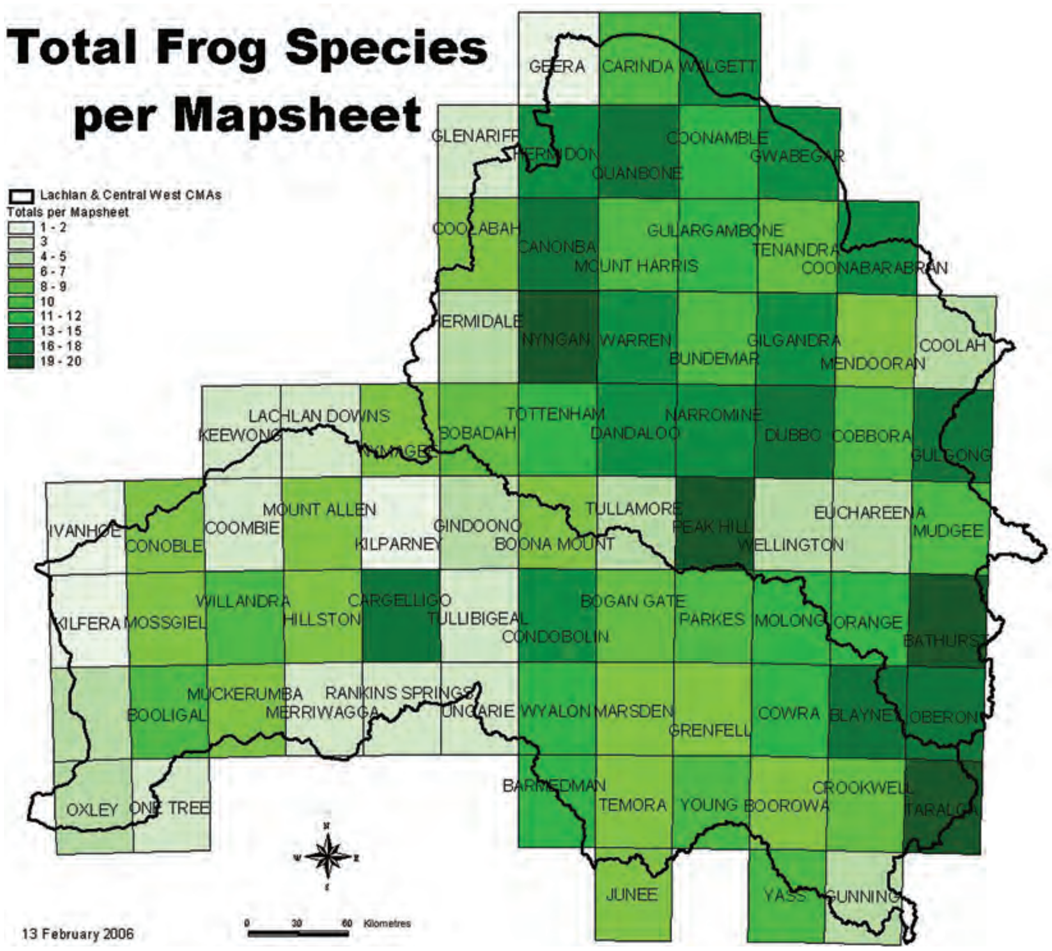


Figure 11: Total number of amphibian species recorded for each mapsheet on the Central West and Lachlan CMAs

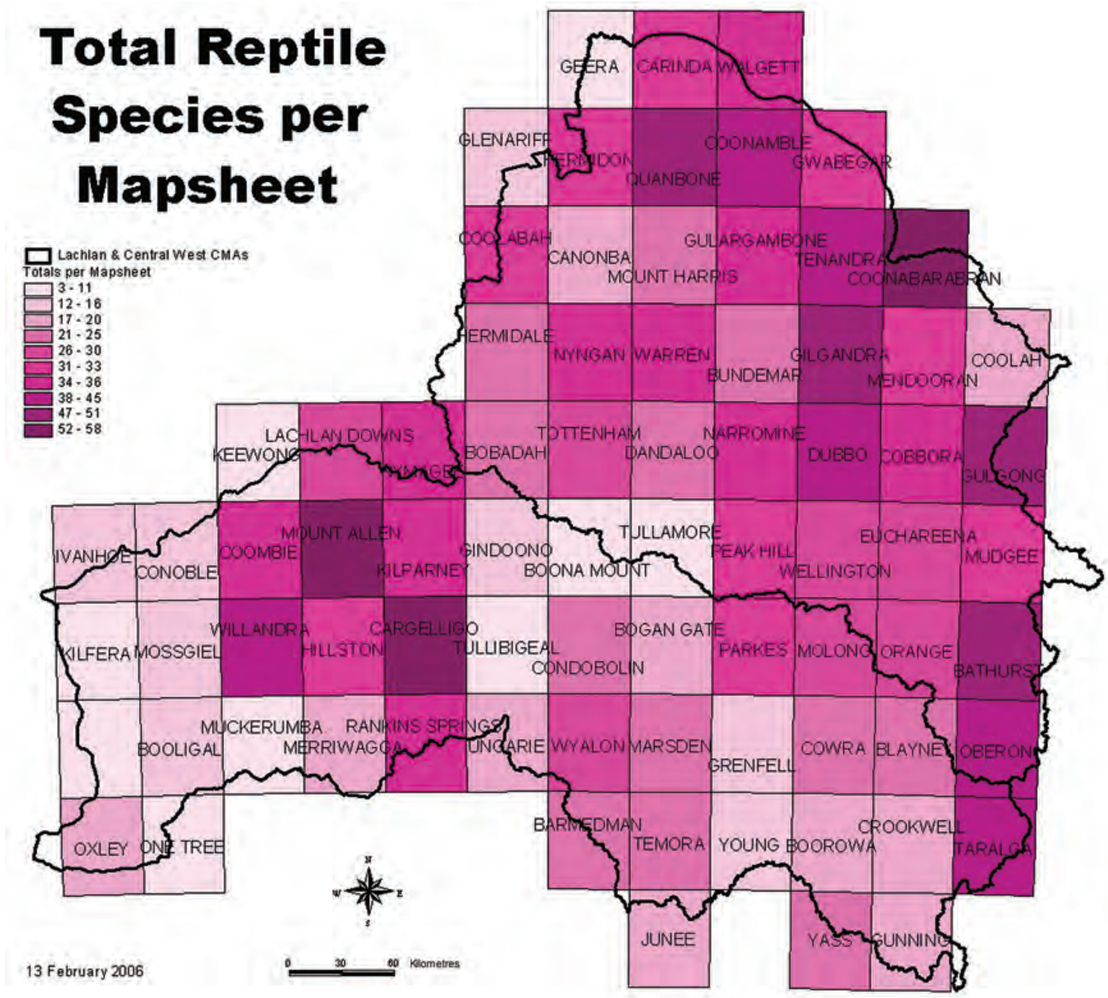


Figure 12: Total number of reptile species recorded for each mapsheet on the Central West and Lachlan CMAs.

Pattern analysis of terrestrial faunal distributions within the Central West and Lachlan catchments

There has been no previous analysis of the co-occurrence of faunal species in the Central West and Lachlan catchment areas to describe the communities that may exist in this region. A pattern analysis of the faunal distribution data from the database was carried out using PATN software (Belbin 2003). The 1:100,000 mapsheets (each 30 minutes of latitude and longitude in size and approximately 2,500km^2) were the quadrat base for the analysis.

A species list was created for each mapsheet with the species recorded as either present (1) or absent (0). Abundance measures such as counts or the number of records per mapsheet can be used in pattern analysis but were not used here due to the large variation in the sources of data that were used to construct the fauna database. Six mapsheets with a low number of species records (Canbelego, Coolamon, Cootamundra, Goulburn, Katoomba, Paika) were excluded from the analysis. These mapsheets are all on the boundaries of the catchments. The data matrix of fauna species by mapsheet of occurrence was separated into bird fauna and other vertebrate fauna i.e. mammals, reptiles and frogs. This distinction was made because of the generally higher mobility of bird fauna when compared with the other vertebrates and their much greater sampling intensity across the catchments. The other vertebrates tend to occupy a much more limited range and show tighter association with vegetation type and substrate type.

A set of confirmatory attributes was generated for each mapsheet based on the climatic surfaces for Australia (Busby 1991). These were:

- easting,
- northing,
- maximum rainfall,
- maximum temperature,
- mean temperature,
- minimum rainfall,
- minimum temperature,
- rainfall total,
- rainfall coolest quarter,
- rainfall coefficient of variation,
- rainfall driest quarter,
- rainfall warmest quarter,
- rainfall wettest quarter,
- temperature coolest,
- temperature driest quarter,
- temperature range,
- temperature warmest quarter, and
- temperature wettest quarter.

The default routines from the PATN classification software were used to identify terrestrial fauna associations. The classification metric was the Bray-Curtis measure of association and the fusion of these associations was by the sequential agglomerative hierarchical combinatorial technique called flexible UPGMA (Belbin 2003). Faunal communities that characterised the associations were determined by inversion of the data matrix and classification using the 'Two-step' association metric and fusion using flexible UPGMA with Beta=0. Dendrograms were prepared and group definitions prepared by interpretation of the species by mapsheet two-way table. Group statistics for the confirmatory attributes were calculated using the group definitions from the fauna associations.

Avian associations

Bird species were classified into eight associations and the distribution of these associations across the catchments is shown in Figure 13. The level of association between the groups is provided in the Dendrogram in Figure 14. The primary division of the bird communities found in the two catchments separates the Bassian bird species of the moister ranges and coast from the Eyrean birds that prefer the drier inland regions and runs down the boundary between the plains and the slopes. Of the three bird associations most strongly influenced by Bassian species, the Eastern Highlands association (pale blue on the map) contains the largest number of eastern species. The Western Slopes association (purple on the map) is closely associated but is enriched by overlap with Eyrean species at the eastern edge of their range. The seven mapsheets that form the Eastern Edge association (grey on the map) are dissimilar at a high level largely because they are insufficiently sampled.

The Eyrean species form five associations with two Western Plains associations (pink and gold on the map) separating at a moderate level of dissimilarity. The Western Plains 2 association (gold on the map) contains only three mapsheets all of which are poorly sampled. The Riverina Shrublands association (olive on the map) is a tightly defined group that separates from the remaining two groups of the western plains. The Western Woodlands (pale yellow on the map) and Macquarie Floodplains (light green on the map) associations have a high degree of similarity in their bird species but are spatially discrete.

A number of bird species groups or communities were well defined by their co-occurrence following a two-step analysis of the inverted data matrix. These can be used to characterise the associations described above. By far the largest group defined were the ubiquitous bird species which are distributed across all mapsheets in the two catchments and do not provide any discrimination between communities. This group comprised 157 species

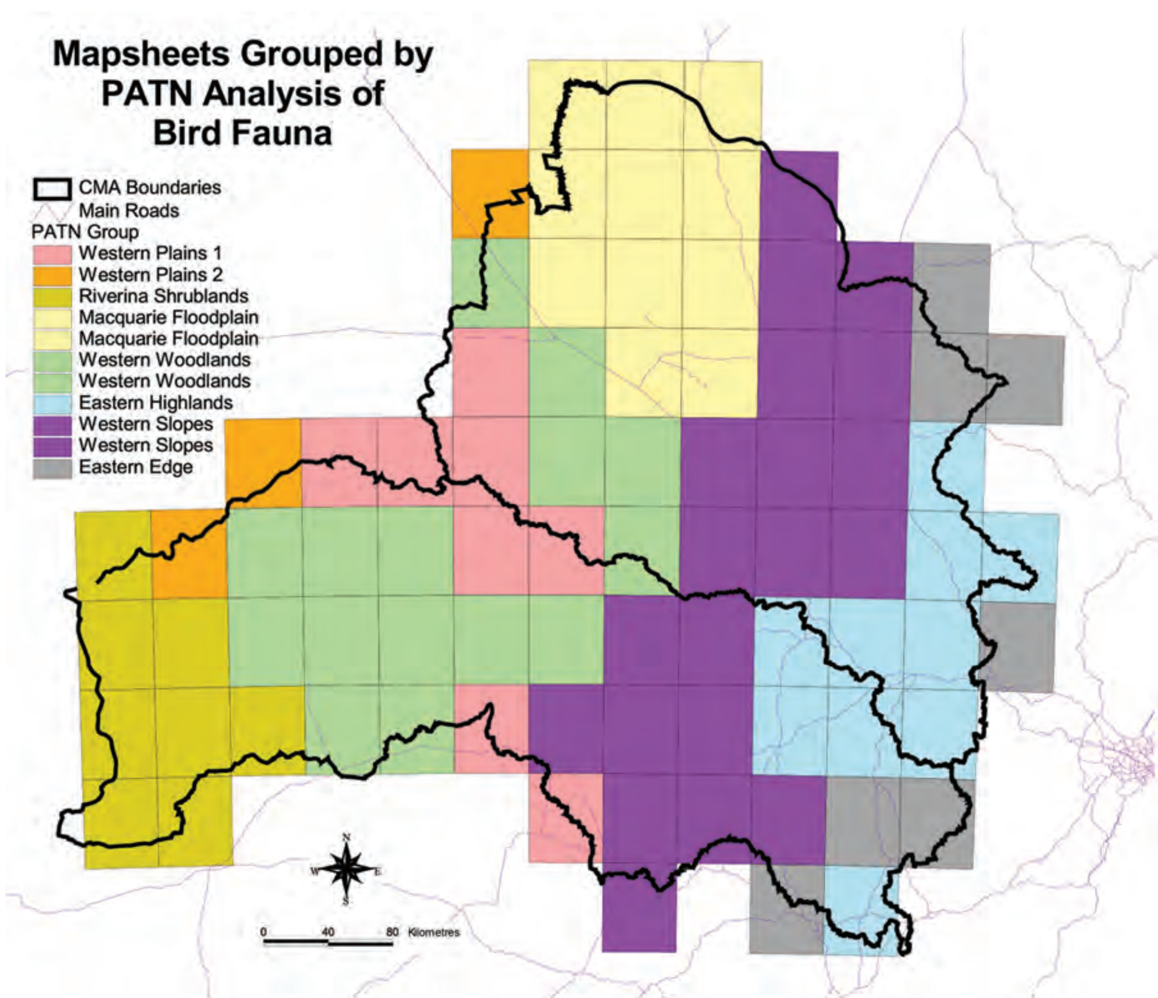


Figure 13: Distribution of the eight avian associations across the Central West and Lachlan catchment areas.

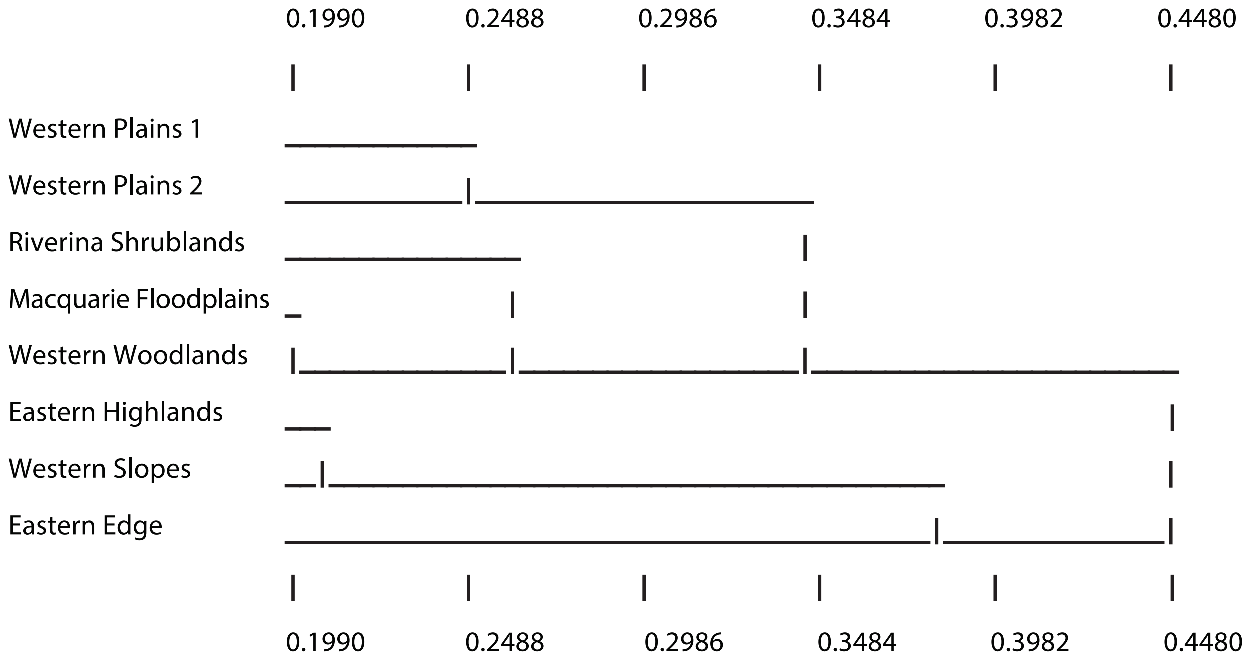


Figure 14: Dendrogram of the level of association between the eight bird groups in the Central West and Lachlan catchments.

listed in Table 3. The second distinct group is the Bassian bird species, 66 in total, that characterise the Western Slopes and Eastern Edge associations and a subset of this group clearly defines the Eastern Highlands association (Table 4). Eyrean species characteristic of the five western bird associations (18 species) are given in Table 5 and these species also can be found in the Western Slopes Association. A unique group of mallee bird species (four species) are also found in the Western Woodland and Western Plains Associations (Table 6). Waterbirds are also characteristic of all associations except for the Western Plains Association (Table 7).

Classification of the climatic variables as confirmatory attributes showed that both temperature and rainfall variables were strongly correlated with the eight bird associations. The strongest correlations for each mapsheet were with Minimum Rainfall, Rainfall Total and Rainfall in the Driest Quarter and reflect the east-west gradient in rainfall across the catchments.

Other terrestrial fauna

The other terrestrial fauna (amphibians, reptiles and mammals (including bats)) were classified into nine associations and the distribution of these associations across the catchments is mapped (Figure 15). The dendrogram indicating the level of association between the nine groups is in Figure 16.

The first three groups to separate out in the classification are the Riverina Plains (pale blue on the map), the Riverina Edges (light purple on the map) and the Southern Edges Associations (grey on the map). These associations have all been under sampled for terrestrial fauna although the Riverina Plains Association is spatially coherent and may have naturally low species numbers. The remaining five associations split at a fairly high level into a Highlands fauna and faunas of the Slopes and Plains. The Highlands Association (gold on the map) which separates from the Southern Highlands Association (olive on the map) is more poorly sampled. The Mallee Sandplain Association separates off first and is a distinctive group in the western region of the catchments but extensive clearing may have led to this community being under-sampled. The Western Slopes Association (pale pink on the map) is distinctive at a moderate level and the two Western Plains Associations (pink on the map) separate out because the three mapsheets that make up the second association are poorly sampled.

The terrestrial faunal species that characterise these associations were determined by using the two-step association metric. The largest group is formed by the ubiquitous species that are distributed throughout the Central West and Lachlan catchments (see Table 8). The species group that characterises the Highland groups is set out in Table 9 and contains many east coast species. The Mallee Sandplain Association is characterised by a large group of reptiles shown in Table 10 and species that are found generally on the Western Slopes and Plains are listed in Table 11. Classification of the climatic variables as confirmatory attributes demonstrated that rainfall variables were strongly correlated with the nine terrestrial fauna associations but temperature was not correlated so strongly. The strongest correlations for each mapsheet were with Maximum Rainfall, Rainfall Total and Rainfall in the Warmest Quarter and reflect the east-west gradient in rainfall across the catchments.

Faunal communities in the Central West and Lachlan CMAs

The vertebrate fauna of the Central West and Lachlan CMAs form broad associations that show a spatial cohesion when mapped at the 1:100,000 mapsheet scale. These faunal associations provide insights into the origins of local fauna, highlight those mapsheets in the catchments that are enriched by overlapping faunal groups and provide a sound basis for the reconstruction of prior faunas at a

Table 3. Ubiquitous bird species (n=157)

Apostlebird	Fairy Martin	Red-rumped Parrot
Australasian Grebe	Fan-tailed Cuckoo	Restless Flycatcher
Australasian Shoveler	Galah	Richard's Pipit
Australian Hobby	Gilbert's Whistler	Rock Dove
Australian Magpie	Glossy Ibis	Royal Spoonbill
Australian Owlet-nightjar	Golden Whistler	Rufous Songlark
Australian Pelican	Great Cormorant	Rufous Whistler
Australian Raven	Great Egret	Sacred Kingfisher
Australian Ringneck	Grey Butcherbird	Shining Bronze-Cuckoo
Australian White Ibis	Grey Fantail	Silver Gull
Australian Wood Duck	Grey Shrike-thrush	Silvereye
Banded Lapwing	Grey Teal	Singing Bushlark
Barn Owl	Grey-crowned Babbler (eastern subspp)	Singing Honeyeater
Bar-shouldered Dove	Ground Cuckoo-shrike	Southern Boobook
Black Falcon	Hardhead	Southern Whiteface
Black Honeyeater	Hoary-headed Grebe	Spiny-cheeked Honeyeater
Black Kite	Hooded Robin	Spotted Harrier
Black Swan	Horsfield's Bronze-Cuckoo	Spotted Nightjar
Black-eared Cuckoo	House Sparrow	Spotted Pardalote
Black-faced Cuckoo-shrike	Inland Thornbill	Straw-necked Ibis
Black-faced Woodswallow	Intermediate Egret	Striated Pardalote
Black-fronted Dotterel	Jacky Winter	Striped Honeyeater
Black-shouldered Kite	Laughing Kookaburra	Stubble Quail
Black-tailed Native-hen	Little Black Cormorant	Sulphur-crested Cockatoo
Black-winged Stilt	Little Button-quail	Superb Parrot
Blue Bonnet	Little Corella	Tawny Frogmouth
Blue-faced Honeyeater	Little Eagle	Tree Martin
Brown Falcon	Little Friarbird	Varied Sittella
Brown Goshawk	Little Pied Cormorant	Variegated Fairy-wren
Brown Quail	Little Raven	Wedge-tailed Eagle
Brown Songlark	Magpie-lark	Weebill
Brown Treecreeper	Masked Lapwing	Welcome Swallow
Brown-headed Honeyeater	Masked Woodswallow	Western Gerygone
Budgerigar	Mistletoebird	Whiskered Tern
Chestnut-rumped Thornbill	Nankeen Kestrel	Whistling Kite
Cockatiel	Nankeen Night Heron	White-backed Swallow
Collared Sparrowhawk	Noisy Friarbird	White-breasted Woodswallow
Common Bronzewing	Noisy Miner	White-browed Babbler
Common Starling	Olive-backed Oriole	White-browed Woodswallow
Crested Bellbird	Pacific Black Duck	White-faced Heron
Crested Pigeon	Painted Honeyeater	White-fronted Chat
Crimson Chat	Pallid Cuckoo	White-necked Heron
Darter	Peaceful Dove	White-plumed Honeyeater
Diamond Dove	Peregrine Falcon	White-throated Needletail
Diamond Firetail	Pied Butcherbird	White-winged Chough
Dollarbird	Pied Cormorant	White-winged Triller
Double-barred Finch	Pink-eared Duck	Willie Wagtail
Dusky Woodswallow	Rainbow Bee-eater	Yellow Thornbill
Eastern Rosella	Red-backed Kingfisher	Yellow-billed Spoonbill
Eastern Yellow Robin	Red-capped Robin	Yellow-plumed Honeyeater
Emu	Red-chested Button-quail	Yellow-rumped Thornbill
Eurasian Coot	Red-kneed Dotterel	Yellow-throated Miner
		Zebra Finch

Table 4. Bassian bird species characteristic of Western Slopes, Eastern Highlands and Eastern Edge Associations (n=66)

All three associations	Little Wattlebird	White-throated Nightjar
Australian King-Parrot	Long-billed Corella	White-throated Treecreeper
Azure Kingfisher	Mallard	Yellow-faced Honeyeater
Brown Thornbill	Musk Lorikeet	Yellow-tailed Black-Cockatoo
Brush Cuckoo	Powerful Owl	Yellow-tufted Honeyeater
Channel-billed Cuckoo	Rainbow Lorikeet	**Eastern Highlands**
Chestnut-rumped Heathwren	Red-browed Finch	Bassian Thrush
Cicadabird	Red-browed Pardalote	Beautiful Firetail
Common Koel	Red-browed Treecreeper	Black-faced Monarch
Common Myna	Regent Honeyeater	Brown Gerygone
Crimson Rosella	Rose Robin	Brush Bronzewing
Eastern Spinebill	Rufous Fantail	Crescent Honeyeater
Eurasian Tree Sparrow	Satin Flycatcher	Eastern Whipbird
European Goldfinch	Scaly-breasted Lorikeet	Large-billed Scrubwren
European Greenfinch	Scarlet Honeyeater	Lewin's Honeyeater
Forest Kingfisher	Scarlet Robin	New Holland Honeyeater
Fuscous Honeyeater	Skylark	Rockwarbler
Gang-gang Cockatoo	Spotted Quail-thrush	Satin Bowerbird
Grey Currawong	Spotted Turtle-Dove	Superb Lyrebird
Grey Goshawk	Striated Thornbill	White-cheeked Honeyeater
King Quail	Swift Parrot	Wonga Pigeon
Leaden Flycatcher	White-browed Scrubwren	Yellow-throated Scrubwren
Little Lorikeet	White-naped Honeyeater	

Table 5. Eyrean bird species characteristic of the Western Plains, Riverina Shrublands, Macquarie Floodplains, Western Woodlands and western Slopes Associations (n=18)

Major Mitchell's Cockatoo	Australian Bustard
Mulga Parrot	Brolga
Little Crow	Plumed Whistling-Duck
Spotted Bowerbird	Letter-winged Kite
White-winged Fairy-wren	Black-breasted Buzzard
Blue-winged Parrot	Red-winged Parrot
Splendid Fairy-wren	Pale-headed Rosella
White-fronted Honeyeater	Little Woodswallow
Grey-fronted Honeyeater	Malleefowl

Table 6. Mallee bird species characteristic of the Western Woodlands and Western Plains (n=4)

Chestnut Quail-thrush	Shy Heathwren
Red-lored Whistler	Southern Scrub-robin

landscape level. There is also a clear connection between the faunal associations and the Broad Habitat Types that occur on each mapsheet. The analysis of the confirmatory attributes found that there was a strong correlation between the associations and the rainfall gradients across the catchments. These gradients determine the complexity of the habitats that can be sustained in a given region and this strongly influences the species that are present. There was a weaker relationship between the associations and the geomorphological aggregations used to create bioregions but enough to show that substrate is equally important in determining distributions for most ground dwelling species.

Table 7. Wetland bird species characteristic of the Riverina Shrublands, Macquarie Floodplains, and Western Slopes associations but absent from the Western Plains Association (n=21).

Australasian Bittern	Marsh Sandpiper
Australian Pratincole	Masked Owl
Australian Shelduck	Orange Chat
Australian Spotted Crake	Painted Snipe
Baillon's Crake	Pied Honeyeater
Black-necked Stork	Plains-wanderer
Blue-billed Duck	Red-capped Plover
Common Greenshank	Red-necked Avocet
Freckled Duck	Sharp-tailed Sandpiper
Little Bittern	Wandering Whistling-Duck
Magpie Goose	

Further analysis of these patterns of distribution using ordination techniques would allow for a predictive approach to defining the distribution of key species throughout the catchments.

Conservation status

In addition to the listing of species by the Commonwealth *EPBC Act 1999* and the NSW *TSC Act 1995*, we have assessed the regional conservation status of the species recorded within the Lachlan and Central West catchment areas. Six categories were defined for this purpose: Secure (Se), Declining (D), Regionally Vulnerable (RV), Regionally Endangered (RE), Regionally Extinct (REx) and extinct in NSW (Table 12). Species determined as REx and Extinct in NSW

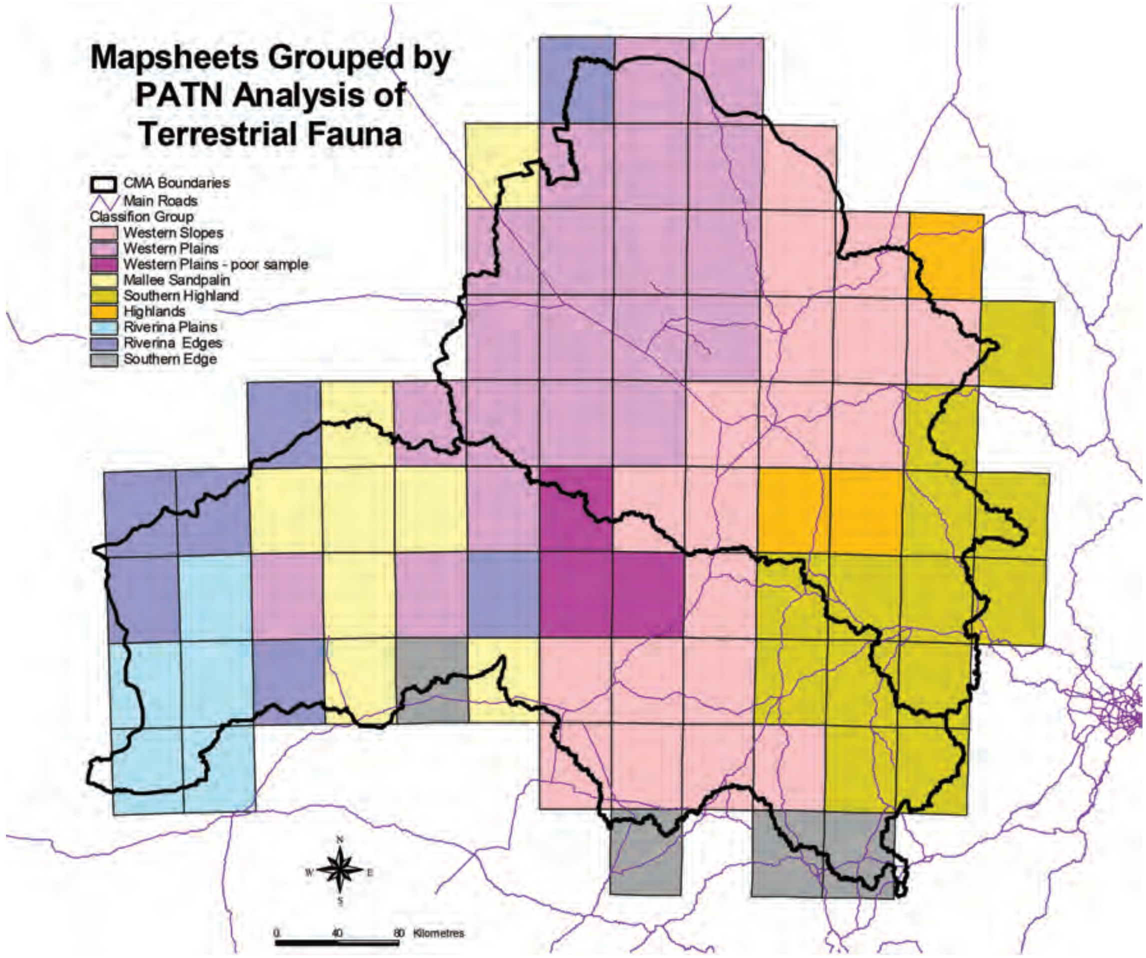


Figure 15: Distribution of the nine associations of mammals, reptiles and amphibians across the Central West and Lachlan catchment areas.

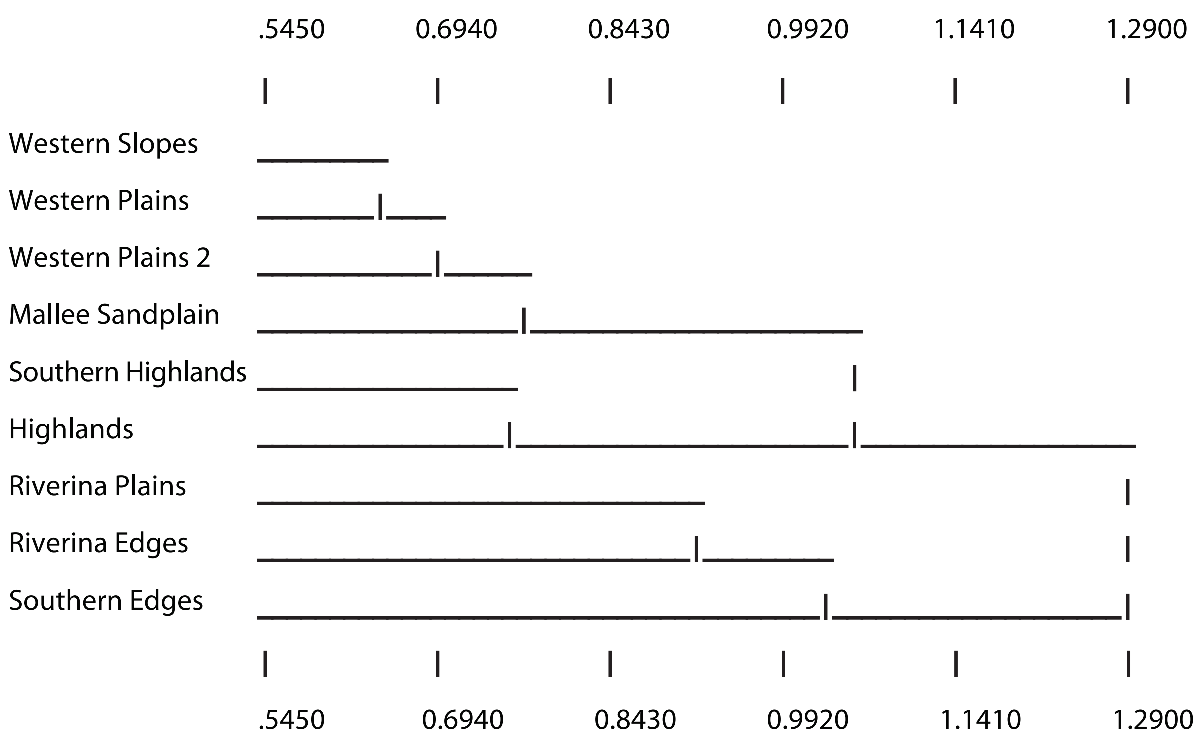


Figure 16: Dendrogram of the level of association between the nine groups of mammals, reptiles and amphibians in the Central West and Lachlan catchments

Table 8. Ubiquitous terrestrial fauna across the two catchments (n=60)

Amphibians	*Pogona barbata*	*Mormopterus sp. 3 (big penis)*
Crinia parinsignifera	*Pseudechis guttatus*	*Mus musculus*
Crinia sloanei	*Pseudonaja textilis*	*Myotis macropus*
Limnodynastes ornatus	*Pygopus lepidopodus*	*Nyctophilus geoffroyi*
Limnodynastes tasmaniensis	*Ramphotyphlops bituberculatus*	*Nyctophilus corbeni (formerly) timoriensis*
Litoria caerulea	*Ramphotyphlops proximus*	*Oryctolagus cuniculus*
Litoria latopalmata	*Ramphotyphlops wiedii*	*Ovis aries*
Litoria peronii	*Strophurus williamsi*	*Petaurus norfolcensis*
Reptiles	*Tiliqua rugosa*	*Pteropus scapulatus*
Acanthophis antarcticus	*Tiliqua scincoides*	*Saccolaimus flaviventris*
Amphibolurus nobbi	*Underwoodisaurus milii*	*Sminthopsis crassicaudata*
Ctenotus robustus	*Varanus varius*	*Sminthopsis murina*
Ctenotus strauchii	*Vermicella annulata*	*Sus scrofa*
Demansia psammophis	Mammals	*Tachyglossus aculeatus*
Diplodactylus vittatus	*Antechinus flavipes*	*Tadarida australis*
Egernia striolata	*Capra hircus*	*Trichosurus vulpecula*
Furina diadema	*Chalinolobus gouldii*	*Vespadelus vulturnus*
Lialis burtonis	*Felis catus*	*Vulpes vulpes*
Morelia spilota	*Lepus capensis*	*Wallabia bicolor*
Morethia boulengeri	*Macropus giganteus*	
Parasuta dwyeri	*Macrotis lagotis*	
Parasuta spectabilis	*Mormopterus planiceps*	

Table 9. Species that characterise the highland groups (n=52)

Amphibians	*Egernia cunninghami*	Mammals
Litoria aurea	*Egernia saxatilis*	*Antechinus stuartii*
Litoria booroolongensis	*Eulamprus heatwolei*	*Antechinus swainsonii*
Litoria citropa	*Eulamprus tympanum*	*Cervus dama*
Litoria dentata	*Hemiergis decresiensis*	*Falsistrellus tasmaniensis*
Litoria ewingii	*Lampropholis delicata*	*Miniopterus schreibersii*
Litoria lesueuri	*Lampropholis guichenoti*	*Mormopterus norfolkensis*
Litoria phyllochroa	*Niveoscincus coventryi*	*Nyctophilus gouldi*
Litoria verreauxii	*Notechis scutatus*	*Perameles nasuta*
Mixophyes balbus	*Phyllurus platurus*	*Petauroides volans*
Uperoleia laevigata	*Pseudemoia entrecasteauxii*	*Petaurus australis*
Reptiles	*Pseudemoia spenceri*	*Rattus fuscipes*
Acritoscincus duperreyi	*Ramphotyphlops nigrescens*	*Rattus lutreolus*
Acritoscincus platynota	*Rhinoplocephalus nigrescens*	*Scoteanax rueppellii*
Amphibolurus muricatus	*Saiphos equalis*	*Scotorepens orion*
Aprasia parapulchella	*Saproscincus mustelinus*	*Vespadelus darlingtoni*
Austrelaps ramsayi	*Tiliqua nigrolutea*	*Vespadelus pumilus*
Austrelaps superbus	*Varanus rosenbergi*	*Vespadelus regulus*
Cryptoblepharus virgatus		

Table 10. Characteristic species of the Mallee Sandplain Association (n=26).

Reptiles	*Egernia inornata*	*Strophurus intermedius*
Ctenophorus fordi	*Eremiascincus richardsonii*	*Tiliqua occipitalis*
Ctenophorus pictus	*Lucasium damaeum*	*Uperoleia capitulata*
Ctenotus atlas	*Morethia obscura*	Mammals
Ctenotus leonhardii	*Parasuta nigriceps*	*Lagorchestes leporides*
Ctenotus regius	*Pogona vitticeps*	*Macropus fuliginosus*
Ctenotus schomburgkii	*Pseudonaja nuchalis*	*Ningaui yvonneae*
Delma australis	*Ramphotyphlops australis*	*Vespadelus baverstocki*
Delma butleri	*Rhynchoedura ornata*	
Diplodactylus steindachneri	*Strophurus ciliaris*	

Table 11. Species of terrestrial fauna generally found in the Western Slopes and Western Plains associations (n=39)

Amphibians	*Ctenotus ingrami*	*Pseudechis australis*
Cyclorana alboguttata	*Delma inornata*	*Pygopus schraderi*
Cyclorana platycephala	*Denisonia devisi*	*Ramphotyphlops ligatus*
Cyclorana verrucosa	*Diplodactylus tessellatus*	*Suta suta*
Limnodynastes fletcheri	*Emydura macquarii*	*Tympanocryptis tetraporophora*
Limnodynastes salmini	*Gehyra dubia*	*Varanus gouldii*
Litoria rubella	*Gehyra variegata*	*Varanus tristis*
Neobatrachus sudelli	*Hemiaspis damelii*	**Mammals**
Notaden bennettii	*Heteronotia binoei*	*Antechinomys laniger Chalinolobus picatus*
Uperoleia rugosa	*Lerista muelleri*	*Macropus rufus*
Reptiles	*Lerista punctatovittata*	*Mormopterus sp. 4 (little penis)*
Brachyurophis australis	*Lophognathus burnsi*	*Planigale tenuirostris*
Cryptoblepharus carnabyi	*Menetia greyii*	*Scotorepens balstoni*
Ctenotus allotropis	*Oedura marmorata*	*Scotorepens greyii*

were determined from species data obtained during this study. Species in each of the first four categories was determined using the opinion of experts with long term experience within the region and supplemented by reference to data from this and previous studies (e.g. Goldney 1987). The chosen experts were scientists or naturalists who had lived and/or surveyed widely within the region and who were very familiar with one or more of the four vertebrate groups, particularly within the period 1980 to 2005 since the similar analysis published by Goldney (1997).

Each expert was interviewed after being provided with a complete set of species distribution maps for each 1:100,000 mapsheet in the study area. Additional naturalists and scientists were consulted about particular species when this was deemed necessary. Specialists consulted included: Richard Wells (amphibians and reptiles), Ian McCartney (Amphibians and reptiles), Gavin Waters (reptiles), Neville Schrader (birds), Greg Richards (bats) and David Goldney (all terrestrial vertebrate groups). The assessment for each species was for the Lachlan and Central West catchments as a whole.

Of the 572 native species (excluding fish), 16% are listed under Commonwealth and NSW legislation and a further 60% have been judged using the above process to be regionally vulnerable or endangered at a regional scale (Table 12). Trends of abundance within the catchments were also assessed and of all vertebrate fauna recorded in the region only 33% were assessed as secure while 66% are believed to be declining (Table 12). The declining species include some species currently considered secure but which may be trending towards being vulnerable. There are also 25 introduced terrestrial species.

Fish have not been included in this analysis but of the 16 native species known to occur in the region five have been listed under the *TSC Act 1995* and three under the *EPBC Act 1999*. There are also seven introduced fish species in the region.

Halting the decline

"Yarran and Myall and Box and Pine
Twas axe and fire for all;
They scarce could tarry to blaze the line
Or wait for the trees to fall."

This is the third verse of the A. B. Patterson poem "Song of the Wheat", first published in 1914 (Patterson 1914). Patterson clearly observed the very rapid clearing that was initiated by the expansion of wheat cropping across NSW, right into the western parts of the state as indicated by

Table 12. Summary statistics for the vertebrate fauna recorded for the Central West and Lachlan catchment areas. This includes the total number of species, native and exotic and the sub-division into the four vertebrate taxa. The number of species listed under both the *TSC Act 1995* and the *EPBC Act 1999* and an expert assessment of the status of all other native species occurring in these catchments is also provided. Se = secure; D = declining; RV = regionally vulnerable; RE = regionally endangered; REx = regionally extinct. It is important to note that a declining species may currently be secure but may be trending towards a vulnerable status.

Central West and Lachlan Catchments: Summary statistics for vertebrate fauna (excluding fish)													
Faunal group	Number of species		TSC Act		EPBC Act			Native species only					
								Species status					
	Native	Exotic	V	E	V	E	CE	Se	D	RV	RE	REx	Extinct NSW
Frogs	38	0	2	3	4			9	23	19	8	3	
Reptiles	128	0	5	1	2			53	59	50	15		
Birds	329	12	31	3	2	2		99	275	133	70	7	
Mammals	77	13	18	3	5	2		25	25	16	16	6	9
Totals	572	25	56	10	13	4		186	382	218	109	16	9

the tree species he lists. The poem suggests urgency and a dramatic change in the landscape.

The clearing and landuse history of the central west of NSW has resulted in severely reduced habitat availability. Overall there is only one third of the original vegetation communities still present, but as is clearly evident from the 1:100,000 BHT maps, this is very unevenly distributed across the catchment landscape (Figure 4). In addition whether the remnant vegetation represents available habitat is unknown. Each BHT has been subjected to a different degree of loss and the distribution of remnants (patch size and fragmentation) is extremely variable. Consequently each of the BHTs has a different capacity, within this landscape, to provide suitable habitat for the long term maintenance of healthy, actively reproducing populations and communities.

Habitat conservation trends within the Central West and Lachlan CMAs are generally negative. With the reduction in rates of clearing since 1995, total loss of available habitat has been reduced. However, with the focus on clearing as the threatening process, grazing is continuing to have a serious impact. While this is recognised as an issue, the public pressure to change attitudes towards this issue has not occurred. In the present context habitat quality is continuing to degrade and remnant habitat is not providing the appropriate range of habitat features required to support diverse, healthy, appropriate faunal communities for each habitat type.

With the data available it is impossible to provide any quantified assessment of vertebrate abundance. The confounding problems include the fact that the records have been collected over a very long period of time and species abundance is most likely to have changed in response to the continuing action of threatening and degrading processes. Add to this the fact that the number of records in the database for each mapsheet is directly proportional to the effort expended. This may be through systematic surveys or observational data from credible observers. If observational data are more common than survey data, then there is likely to be a greater representation of bird data compared with the other terrestrial taxa. Relative abundance has been incorporated into this study through our development of regional conservation status through expert opinion. While some of these assessments may be debated, with the potential loss of species and populations from our landscape it is critical that the management authorities invoke the precautionary principle in developing their strategies, as required by almost all state and national environmental legislation.

Populations of species wax and wane numerically and spatially in response to very complex environmental factors. Each species occupies a specific ecological niche that helps to define its' and the population's role in contributing to ecosystem processes and in maintaining ecosystem health and resilience (Swihart *et al.* 2003; Swihart *et al.* 2006). Populations may be widespread, increasing or decreasing in area, temporarily stable but always dynamic. They may be more or less continuous in the landscape but rarely evenly spread and often clumped. However most populations are discontinuous and made up of meta-populations of varying viability linked by migration. Meta-populations rather than whole populations tend to dominate landscapes where core habitat becomes fragmented and when completely isolated may be the forerunner of local extinction and eventually population extinctions over a range of scales (Hanski 1998; Hilty *et al.* 2006; Taylor 1990).

This assessment of the status of vertebrate fauna and available habitat was carried out towards the end of a period of below average rainfall. Since then rainfall has increased with some exceptional falls recorded in some parts of these catchments. While there has been no further analysis or evaluation of the data and it is probable that breeding success has been higher for many species, the fundamental landscape repair required to produce a long term increase in abundance and distribution is still required.

In the Central West and Lachlan catchment areas we are effectively witnessing the process of desertification at work and the development of an increasingly dysfunctional landscape. Major cycles are disrupted at micro and landscape scales to the extent that resources are leaking from the landscape and energy flows have changed. The key losses are water (the landscape is drying), organic carbon (the landscape is losing the ability to store water), sediment and nutrients and these losses are significantly higher than pre-European base loads. More solar energy is captured within the landscape leading to landscape heating. Malfunctioning processes (ecosystem functions) lead to species losses.

The resilience of the landscape of this catchment is difficult to determine but the evidence suggests that there has been an incremental loss of resilience since European settlement and the capacity to self repair has been lost or greatly diminished. In order to obtain a possible indication of landscape resilience we assessed the condition of each 1:100,000 mapsheet based on each of the following parameters: threatening processes, vertebrate species diversity (for fish, amphibians, reptiles, birds and mammals), habitat retention, habitat variability, habitat condition, connectivity, riparian and stream condition, and ecosystem function and landscape resilience. We then determined a condition trend and the capacity for ecological repair at both farm scale and landscape scale (Table 13) The methodology used for this assessment is provided in Goldney *et al.* (2007) (Volume 1 Section 5 and Vol 4). Of the 89 sheets analysed, none were assessed as being in very good condition, six (6.7%) were rated as being in good condition, 48 (53.9%) were rated as being in medium condition and 35 (39.3%) were rated as being in bad condition.

If we are to manage the landscape to avoid loss of overall biodiversity we must begin with fundamental landscape repair. The use of a single species conservation approach, as is the focus of the *TSC Act* (1995), must be secondary to or concurrent with urgent landscape repair priorities. It is essential that an ecosystem approach be designed and implemented. Without the implementation of repair strategies and halting the degrading processes, there will

Table 13. Condition of 1:100,000 map sheets in the Central West and Lachlan CMAs. A=very good condition; B=good condition; C=medium condition; D=bad condition; E=very bad condition

	A	B	C	D	E
CWCMA	0	5	20	18	0
LCMA	0	1	28	17	0
Total	**0**	**6**	**48**	**35**	**0**

be no change in the rate of species losses and declines. We need to move on from amenity plantings with low resilience and often little habitat value to the functional approach. With this approach, every remnant patch of vegetation is a launching pad for species conservation.

Key to an ecosystem approach to halting the loss of vertebrate diversity is a landscape based restoration strategy. This should include slowing of water flows to rehydrate the surrounding land and strategies to encourage the build up of litter and organic matter which will improve the carbon and nutrient status of the soil. Fundamental to this is the enhancement of vegetation cover at all times. A particularly valuable approach is that described by Tongway and Ludwig (2011), including their adaptive learning loop which is a process that enables the adjustment of restoration techniques if goals are not being achieved (Tongway and Ludwig 2011).

In association with the development of strategic plans for landscape repair it is also essential to reinstate on-ground surveys which will not only provide up to date data for the distribution, abundance and conservation status of species and their communities but also a measure of habitat condition and quality. This may not require full trapping surveys in all locations but could include a mixture of trapping surveys in strategic locations and rapid assessment surveys to provide a broader measure.

Although we have painted a rather grim picture of the state of landscape function, and the status of vertebrate species and their habitats in the Central West and Lachlan CMAs, we remain optimistic that we can create a managed landscape that can be optimised for nature conservation and agriculture. These issues of landscape function and status of vertebrates are also not restricted to the central west of NSW (Lunt and Bennett 2000; Fitzsimons *et al.* 2010) but environmental awareness within the population and within farming communities is broadly increasing. Indicative of this is the existence of a significant legislative framework to protect the environment and threatened species within both state and federal jurisdictions and the increasing obligation of local government to plan and execute appropriate conservation outcomes for flora and fauna. The role of Catchment Management Authorities in working with land managers to produce better environmental outcomes is increasingly being accepted and in NSW this is underpinned by more robust Catchment Action Plans based on a sound integration of scientific understanding and community engagement.

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Goldney, D. G., Kerle, J. A. and Fleming M. R. 2007. Status of Vertebrate Fauna and their Habitat in the Central West Catchment. Report to the Central West CMA http://cw.cma.nsw.gov.au/Publications/resources.html.

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APPENDIX 1

Yellow-footed Antechinus *Antechinus flavipes*. This little carnivore survives in suitable remnant habitat including along roadside vegetation surrounded by cleared agricultural and grazing land. Photo, A. Kerle.

Reed beds in the flooded Macquarie Marshes after a combination of good local rainfall and rainfall in the headwaters. Photo, A. Kerle.

APPENDIX I

Flooded red gums in the Macquarie Marshes after recent flooding events. Photo, A. Kerle.

A River Red Gum dated as 960 years old, preserved in a park in Warren, NSW. Large habitat trees across the landscape are a diminishing resource in the central west of NSW. Photo, A. Kerle.

Challenges in this landscape include increasing pressure on remnant trees through firewood collection and degradation by wild pigs. Photo taken western side of Macquarie Marshes. Photo, A. Kerle.

Crooked Creek, an overflow creek from the Macquarie River west of the Macquarie Marshes. These overflow creeks would have flowed only intermittently when river flows were high and flowed over the river bank. Since 1896 this creek has had a constant water flow, changing the ecological function of the creek. Photo, A. Kerle.

APPENDIX I

Goan Swamp, Goonoo Conservation Area north of Dubbo. This remnant woodland is critically important in this cleared landscape, supporting a diverse fauna including several threatened species. Photo, A. Kerle.

Stand of very old Xanthorrea trees in Coolah Tops National Park in the north east of the study area. Photo, A. Kerle.

Diverse landforms of Coolah Tops National Park in the north-east of the study area. Photo, A. Kerle.

Deeply eroded watercourse north of Mudgee. This is a significant problem in the highly dispersive soils found in this region. The erosion of this creek has been initiated by poor road design. Photo, A. Kerle.

APPENDIX I

Impact of clearing in the east of the study area. Soil slumping at break of slope in cleared grazing lands north of Mudgee. Photo, A. Kerle.

Salinity near Ulan north of Mudgee. Photo, A. Kerle.

Large herd of feral goats in grazing land and cypress scrub near Nymagee in western NSW. Photo, A. Kerle.

Eroded creek in degraded grazing land near Nymagee, western NSW. Photo, A. Kerle.

APPENDIX I

Debris accumulation from landscape water flows after heavy rain in Cumbine State Forest near Nymagee NSW. This forest is adjacent to the preceding eroded creek and demonstrated a more functional landscape condition. Photo, A. Kerle.

Cypress pine regrowth in western NSW. This is an example of invasive native shrubs. Photo, A. Kerle.

Large Grey Box in the Cumbine State Forest. Trees of this size are becoming increasingly rare and are critical habitat. Photo, A. Kerle.

Fine scale debris accumulation from cross surface water flows. Such accumulation is critical for nutrient cycling and plant germination. Photo, A. Kerle.

APPENDIX I

Large lace monitor *Varanus varius* Cumbine State forest near Nymagee. Photo, A. Kerle.

Searching for reptiles under building debris in Cumbine State forest during a fauna survey conducted by the National Parks Association. Photo, A. Kerle.

Spotted *Lerista Lerista punctovittata* Cumbine State forest near Nymagee. Photo, A. Kerle.

APPENDIX I

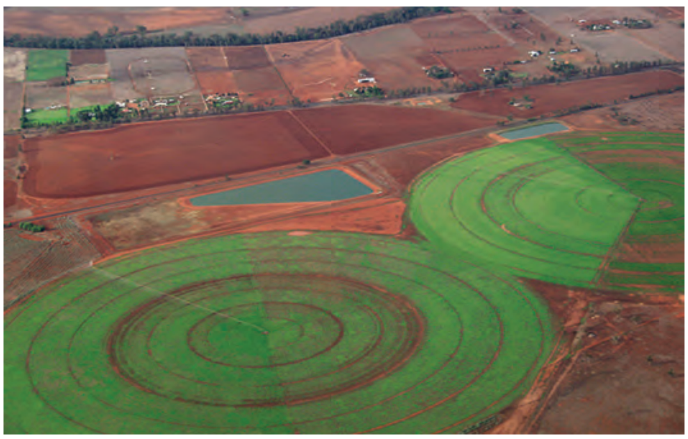
Tree skink *Egernia striolata* Cumbine State forest near Nymagee. Photo, A. Kerle.

Degraded treescape showing dieback in grazing land near Boorowa in the Lachlan Catchment. Photo, A. Kerle.

Large old mugga ironbark surviving in a road reserve near west of Dubbo but threatened by pruning for overhead power lines. Research to age trees like this has yet to be carried out. Photo, A. Kerle.

APPENDIX I

Aerial view of the cleared agricultural landscape in central western NSW with remnant vegetation largely restricted to watercourses and road reserves. Photo, A. Kerle.



Aerial view of the cleared agricultural landscape near Dubbo. Circular patterns are produced by centre pivot irrigation. Photo, A. Kerle.

Foxes are abundant across this landscape and significantly impact the survival of native vertebrate fauna. Photo, A. Kerle.

Decapitated feathertail glider *Acrobates frontalis* found on the ground, potentially captured by yellow-footed antechinus a species also captured in the Cookamidgera area. Photo, A. Kerle.

APPENDIX I

Remnant woodland on Black Rock Ridge south of Orange. Surveys have found that these remnants on ridge country are critically important for vertebrate fauna. Heath monitor *Varanus rosenbergi* was found on this ridge, extending the known range of this species. Photo, A. Kerle.

Grazing lands surrounding Black Rock Ridge, south of Orange in central west NSW. Photo, A. Kerle.

Chenopod shrublands occur in the west of this study area. Photo, A. Kerle.

Poorly managed lands are frequently a significant weed harbour. Yellow-flowered devils claw has an effective dispersal mechanism. Photo, A. Kerle.

APPENDIX I

Carp are now present in huge numbers in inland waterways, including the Macquarie Marshes. Carp gulping air in Crooked Creek. Photo, A. Kerle.

Riparian restoration has been a priority for project funding by the Catchment management authorities. These restoration works occurred on a tributary to Ben Bullen Creek.

Before Photo, C. Miller.

After Photo, C. Miller

APPENDIX I

An intact chain of ponds or swampy meadow in the tablelands of NSW. Photo, D. Goldney.

Davey's Creek near Bathurst NSW, a destroyed swampy meadow. Photo, D. Goldney